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SOME COMMON MISCONCEPTIONS OF EVOLUTION*

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The living world embraces such a variety of form and such a range of structure and mode of life that, to the average man without scientific training, it must always have seemed a great unravelable tangle, inexplicable on any other ground than that of special creation—that some omniscient and omnipotent being made the various forms of life and established them in the world, for his own delectation, if for no other purpose.

But the greater scientific and philosophic minds of the past centuries have been able to discern an order in the midst of this apparent chaos and, from the time of the ancient Greeks, repeated attempts have been made to point out this order and to suggest some more acceptable reason for its existence than to assume that somebody made it all at once and set it up ready to run to the end of time. Naturally, the earlier attempts to convince mankind that there has been a gradual evolution of the present complex order of existence were unsuccessful for want of sufficient knowledge.

It is probable that Aristotle, Lucretius, St. Augustine, Harvey, Buffon, Lamarck, Erasmus Darwin and other great minds of the past apprehended clearly enough the scheme of gradual development of life on the earth, but they lacked sufficient knowledge of the facts to make a convincing argument on a matter apparently so revolutionary. Furthermore, from Augustine on down, they were confronted by a dogmatic theology which effectually blocked the progress of scientific thought for many centuries.

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The scientific men of the past century and a half, especially, have established the following important facts with regard to life on the earth:

1. There has been a gradual development from simpler to more complex forms.
2. There have originated multitudes of new species as well as whole new phyla since the geological record began.
3. Other multitudes of species as well as whole orders have passed out of existence in geological time.
4. These changes have been the result of orderly procedure and not of cataclysmic action.
5. There has been continuity of life and uniformity of biological processes.
6. Untold ages of time have been involved since life first appeared on the earth.

The only satisfactory explanation of these facts is found in organic evolution. All those who have the best right to an opinion on this matter—the scientists who have investigated and carefully weighed all the data, are agreed that there is no other satisfactory method of putting the facts together in logical order. All of the facts and deductions are open to re-examination, but as they have been carefully scrutinized already by large numbers of investigators and from all angles, it is not likely that any different interpretation will be found possible.

Notwithstanding this concensus of opinion among those qualified to judge, there has always been a number of "conscientious objectors" among those untrained in science, on the ground that evolution opposed certain established theological dogmas. A theistic conception of evolution, however, satisfied the more liberal minded of these objectors and there has been a gradual diminution of opposition since the time of Darwin. Recently, however, a well-known, quixotic platform speaker has made a virulent attack on the law of evolution and the weight of his oratory has carried so many people with him, that opposition to evolution has spread like an epidemic through certain portions of this country. If he had chosen, instead, to attack the Copernican theory that the planets revolve around the sun, he would no doubt have convinced many unthinking people and those unfamiliar with the facts. This campaign against a law of nature would be

amusing were it not for the fact that it shows such a deplorable state of ignorance among our supposedly enlightened people, with regard to the progress of science.

It is true that many otherwise highly educated persons do not have a very clear idea of the law of evolution and that many misconceptions are current among them. In the effort to clear up some of these mistaken notions let us consider a few of those which appear to be most commonly held.

It is commonly, but mistakenly, supposed that scientific men are divided in opinion as to the truth of evolution. This idea has arisen from the discussion of certain minor matters, or side issues, such as the mode of origin of species. It may be safely stated that the only questions concerning evolution that are debated by the biological scientists, are those that have to do with the *method* of evolution—the discussion of the means employed by nature in causing the changes that are admitted to have taken place, and the paths along which the advancement occurred. Though there is still much discussion as to just how it has come about, no scientist at the present time has any doubt of the fact of evolution. Furthermore, all will admit that three great interacting factors are to be found in *variation*, however it may be caused; in *selection*, by which inadaptive changes are eliminated and adaptive changes permitted to continue; and in *heredity*, by which any advance, involving the constitution of the organism, may be perpetuated through succeeding generations.

Variations of some sort are necessary, of course, however they may be caused, or there could never be any change and, without change, naturally, no evolution. Moreover, the variations must be of a particular class, for they must be inheritable, and, as far as we know, only those variations are capable of being inherited which involve a change in the germ plasm. The "discontinuous variations" of Bateson and the "mutations of DeVries are the most marked of these germinal variations, but just how small a variation may be and still be inheritable no one has yet discovered. Variation, then, supplies the crude material for evolution.

Natural selection, that much misunderstood and much abused term!—selection is merely another way of stating the fact that variations of all sorts occur and that some of these may benefit an organism, while some others may be harmful to it.

The beneficial variations are of value to the organism in solving its problem of existence and, very naturally, such variations tend to insure that the organism shall live to maturity and through its reproductive period. If a variation is inimical to its possessor, then selection naturally eliminates the organism that possesses such a variation and that is the end of that variation, since, if its possessor does not live, the variation cannot be perpetuated.

Heredity is merely passing on to the next generation any characters which may be a part of the germ plasm of the organism. A species can find no way of continuing a variation that is sufficiently harmful to cause the death of its possessor, or even to pass on for very long a variation that is only mildly disadvantageous. To indicate how important even a slight advantage may be, allow me to quote from Prof. R. C. Punnett; "If a population contains .001% of a new variety, and if that variety has even a 5% selection advantage over the original form, the latter will almost completely disappear in less than a hundred generations." So, heredity becomes an important factor for progress when coupled with variation and selection, in that it gathers up the useful variations and concentrates them in posterity. Or, as Prof. J. A. Thomson puts it, "The true inwardness of heredity is a holding fast of that which is good."

A misconception of heredity lies in the notion that it can accomplish anything more than merely to pass on to future generations what has already become a part of the germ plasm. Just as selection has no evolutionary importance aside from its reaction on variations of different degrees of value in adaptation, so heredity has no place in evolution except as it passes along such characters as have been already selected out as of importance in the life of the organism. Any new variation of the germ plasm, of value, is in this sense selected and, by heredity, becomes a part of the more advanced organism, while any new detrimental variation is swamped by the struggle for existence and is not permitted to be passed along by heredity, because its possessor is eliminated as unfit to meet the conditions of life. It is possible, of course, for a character to be merely useless without being harmful, but such features of an organism must play a very small part in evolution.

Darwin's theory of Natural Selection has been blamed by undiscerning critics as being responsible for the Great War. Unfortunately the term "natural selection," which means nothing more than that one variation may have an advantage over another one under the conditions of nature, has been drawn into bad company by those who have misused it, as, for example, in association with the Neitzschian philosophy of the superman. As a sample, we may quote the following statement from von Bernhardi, "Wherever we look in Nature, we find that war is a fundamental law of evolution. This great verity, which has been recognized in past ages, has been convincingly demonstrated in modern times by Charles Darwin."

Now, Darwin made no such interpretation, and various later biologists have taken exception to this application of his theory to human affairs and especially to war. Thus Thomson wrote, five years before the war, in 1909, in "Darwinism and Human Life": "I find no grounds for interpreting Darwin's 'metaphorical phrase,' the struggle for existence, in any sense that would make it a justification for war between nations." Dr. Chalmers Mitchell also comes to the conclusion (Evolution and the War, 1915) that "They" (modern nations) "differ from the units of zoology and botany in that the individuals composing them are not united by blood-relationship. Even if the struggle for existence were the sole law that had shaped and trimmed the tree of life, it does not necessarily apply to the political communities of men, for these cohere not because of common descent, but because of bonds that are common to the human race."

A former president of this Academy, Prof. Maynard M. Metcalf, stated in his presidential address before the American Society of Zoologists on "Darwinism and Nations," "Human communities, especially, have freed their members from much of the stress of the struggle for existence, by substituting co-operation for rivalry. . . Co-operation may perhaps fairly be said to transcend natural selection as an influence upon the life of highly civilized man. The higher the development of human society, the more dominant becomes the principle of co-operation. Only in the most primitive communities can there be an approach to unrestricted natural selection. Indeed, we know today no such human societies, and it is probable that this stage of social evolution was already passed before man's

ancestors became truly men" (Anatomical Record, Jan., 1918). Thomson again says, "The appeal to human history, which the militarists make confidently, has seemed to many to show that civilization was born out of war. But scientific inquiry does not confirm this conclusion." Havelock Ellis writes (1919) "War probably began late in the history of mankind," and, "War was a result, and not a cause, of social organization." As Thomson points out, "The militarists' appeal to history is not any more convincing than their appeal to biology. The facts are against them in both fields." Finally we should point out, as has been done by various biological writers, that war really is a detriment to both sides, especially between advanced nations, by destroying the best of the younger men, whom the nations at war can by no means afford to lose. Thus war, instead of being contributory to the selecting of the best and the survival of the fittest, too often results in the survival of the unfit on both sides, to the great detriment of the human race.

Thus no one has any cause to shudder at the mere term "natural selection," since, to its gross misapplication as an excuse for war, such as that made use of by ardent militarists, the biologists have as much fault to find as any one. None but the pre-war German philosophers would ever have agreed with von Moltke that "war is a part of God's world order," and the biologist, as much as any one, has a right to feel scandalized by the crass misinterpretation of the selection theory which has been placed upon it.

In a state of nature it is undoubtedly true that "the weaker go to the wall," if by the weaker we mean those that are the least adapted to meet the complex problem of existence, but that does not imply, even in lower animals, that there is usually anything like war between individuals of the same kind. The struggle is confined to the effort of each to maintain itself as an individual, and where competition is keen some have a natural advantage of organization over others and these can better solve the problem of existence while the others fall by the wayside. Of course, the term selection is unfortunate in that in the minds of many persons it is involved with the idea of conscious choice, but no biologist has any difficulty in holding to a proper interpretation of the term.

The notion seems to be prevalent that the proof of evolution hangs on the proof of the method of the origin of species. Now, it happens that the exact cause of the origin of species is still in doubt. This, however, is a comparatively small matter and the law of evolution does not depend upon its solution at all. We have abundant proof that multitudes of species have originated and some of these have been traced through the process of change, even if we do not know what caused the change. Would anyone deny the fact that chickens hatch out of hen's eggs, because the biologist does not pretend to know all the processes involved in the development of the embryo?

It would be extremely interesting to know the causes of the origin of species, but it is not necessary to the fact of evolution. The origin of species in the past is an incontrovertable fact, even if we do not know how they originate. Similarly, organic evolution is an incontrovertable fact, though we may not know all the processes concerned.

In recent years it has often been stated that "Darwinism is discredited" and the average person takes this statement to mean that *evolution is discredited*, for most people cannot seem to get through their heads the fact that *Darwinism* and *evolution are not synonymous*. To what extent Darwinism is discredited, however, depends entirely upon what we mean by the term "Darwinism." Darwin's great contribution was establishing the fact of evolution, than which no greater contribution has ever been made to the fields of science and philosophy.

There is no thought in the minds of scientists of any possibility of controverting evolution, any more than they would deny the Newtonian law of gravitation or the Copernican cosmology. If, however, we merely mean by Darwinism, the same reliance on natural selection of fortuitous variations as the method of origination of new species, which Darwin placed upon it, then we may admit that there are many honest doubters as to the *method* of evolution as stated by Darwin.

However, it is clear that the non-scientific public does not distinguish between the fact of organic evolution and Darwin's explanation of its cause. So, indiscriminating propagandists, opposed to evolution, fix upon the *discussion of Darwin's proposed method* and overlook entirely *the fact which all scientists are agreed upon.*

There are some controversialists again, who misuse, in opposing evolution, the discoveries of Bateson, DeVries, and others, in regard to mutations or larger steps, which throw some doubt on the validity of Darwin's belief in the great importance of minute variations. To accept the mutations of DeVries only means to hasten the process of evolution, since the steps in advance are so much greater than those suggested by Darwin. For, after all, mutations are only germinal, and therefore, hereditary, variations of a more noticeable character, and the acceptance of DeVries' views does not invalidate in the least the importance of the principles of variation, selection and heredity, but only makes possible the progress of evolution at a much more rapid rate than does the Darwinian method. Yet forsooth, because definite mutations are substituted for the minor and fortuitous variations of Darwin, the undiscriminating, ignorant and bigoted proclaim that evolution is overthrown. It would be as truthful to maintain that the Copernican theory of the movement of the planets around the sun is overthrown because a new asteroid is located now and then! Besides it has no bearing on the fact that evolution has taken place.

As to the controversy between those who hold with Darwin and those who agree with DeVries I can see no special difficulty. It may be that they are merely looking at different ends of the same series. Bateson and DeVries at first assumed that mutations must, of necessity, be breaks in the series, of considerable importance. Later investigations, however, have shown that mutations, or hereditary variations, may be much smaller than they were at first supposed to be necessary and, in fact, some of them are much less noticeable than some somatic variations acquired during the life of the individual and not heritable. The difference, which Darwin could not have known, is a qualitative one rather than quantitative, on the basis that to have any evolutionary value, a variation must affect the germ plasm and not merely the body of the individual. On the other hand too great a departure from the normal may have no evolutionary importance because it renders the individual unsuited for life or reproduction and so it is eliminated by natural selection.

It is a common misconception that evolution is a force or power by which things are brought to pass. Even the less dis-

criminating biologists may not be entirely free from this notion, for I recall a little verse which used to be sung at Woods Hole, that Mecca of the biologist, which runs as follows:

"Once I was a Rhizopod, a protoplasmic cell,
I had a little nucleus and oh! I loved it well,
Now I am a man at last, *by evolution's power*,
But oh, my little nucleus! I need thee every hour."

Evolution is merely an explanation of the way things have come to be as they are, together with a statement of the natural laws under which this has taken place. It involves uniformity and continuity in nature and it applies to everything which has undergone change in the course of time.

Some of the confusion in the minds of those untrained in the methods of science is undoubtedly due to the lack of a clear understanding of what is meant by "natural law." A natural law is merely a formula indicating a method of procedure in nature. It is a statement based on the classification of facts and the comparison of their relationships. Civil law, as a man-made rule of conduct implies a restriction and compels conformity, and changes continuously with the varying conditions of human society. Natural laws are merely conclusions drawn from the scientific study of organized series of facts and are immutable except as they are modified by a re-classification and re-statement. A careful reading of the third chapter of Karl Pearson's "Grammar of Science" is recommended to all interested in this matter. "The civil law involves a command and a duty; the scientific law is a description, not a prescription. The civil law is valid only for a *special* community at a *special* time; the scientific law is valid for *all* normal human beings, and is unchangeable so long as their perceptive faculties remain at the same stage of development."

Another misconception of evolution is involved in the idea that it always means an advance of some sort toward higher organization. This idea is contrary to the very method of evolutionary processes. Variations may occur in any direction in any group of organisms, as far as we know, and, theoretically, at least, they are just as likely to be retrogressive as progressive. Secondary simplification is very commonly observed, especially in parasitic organisms.

But what we are especially concerned with in this discussion is progressive evolution in the sense that advances are made in the direction of complexity and the origin of what we are disposed to call higher animals, though we may be guilty of an anthropocentrism in so doing. From the standpoint of the Protozoan we might be considered degenerate, from the fact that our cells have lost their capacity for independent life, and have to live together or not at all. However, it is just this very loss of independence of the individual cell, involving the principle of division of labor and necessitating specialization for the better performance of some process and the co-operation of various parts, that has marked the advance of more complex organisms, whether we may be allowed to call them higher or not.

But variations may occur in all directions and it has often happened that the road to adaptation has lain in the direction of secondary simplification of structure, and selection, in such cases, means the elimination of the more complex, in order to adjust the animal more closely to its environment.

The crayfishes of our American caverns have lost their eyes, but they are highly adapted to a life in total darkness; the sessile ascidians lose nearly all semblance to vertebrate animals, which they clearly possess in the larval stage, by their adaptation to sessile life; the whales and seacows have lost the hind limbs and have taken on a fish-like form in adaptation to aquatic existence. Among parasitic forms we see this carried to the extreme. The tape-worm lacks entirely the intestinal tract, and the parasitic barnacle *Rhizocephala* is so profoundly degenerated that were it not for our knowledge of its development we would not be able to state even its affinities to the Crustacea. These degenerative changes, bringing about the loss of simplification of structures, are just as much the product of evolution as are the modification of a fore limb to a wing in the bird, the highly organized mammalian brain, or the complex social life of bees and ants. As Thomson remarks, "It is plain that evolution may be down as well as up, and that the gates of parasitism and other facile slopes of degenerate life are always open. The tapeworm in its inglorious ease is as much an outcome of evolution as the lark at heaven's gate."

On the other hand, a point on which the man who merely reads about evolution may be at fault, is in thinking that variations are always necessarily fortuitous and occur in a helter-skelter fashion. No doubt many variations are of this nature, but there appear to be others which are directive in their nature from the beginning and which keep on increasing in value with successive generations, the "rectigradations" of H. F. Osborn. The observation of this sort of serial successive variations has led to the suggestion of the principle of *orthogenesis* in evolution, the idea of successive changes along the same line, each going a little farther than its predecessor, so that in a comparatively short time a much greater distance has been compassed than would be possible by mere chance variation in any or all directions. The literature of paleontology is full of such examples, dealing with horns, teeth, limbs, spines, shells and other structures capable of fossilization. The only satisfactory explanation suggested to account for this, seems to be that a small chemical change in the germ plasm may make possible another change of like character and this supply the basis for the next step, and so on. Only on some such basis as this can we explain the evolution of certain structures which make their first appearance in such a small degree that they have no apparent value in selection and yet they keep on varying and advancing along the same line until the structure becomes either adaptive and of value to the organism or inadaptive to a degree sufficient to destroy the species. Such structures may sometimes rise from insignificant, non-selective stages to a condition of much importance to the organism, but, having started to vary in one line the advance may keep on beyond the adaptive condition and finally become a menace to the species. Such conditions of racial senescence are known in numerous examples from the fossil records.

A mistake commonly made by those not engaged in biological work is to think that a great majority of the variations produced must have some value to the organism, since harmful variations are seldom noticed in nature. It is true that beneficial or at least harmless variations are the ones usually noticed, because harmful variations are not perpetuated very long. The biologist with an eye open to these things very often observes them, but they never last long and the more

harmful ones never reach the next generation because they are fatal to the organisms in which they appear. In every species an abundance of such inimical variations may be observed to produce the death of the organism, even before hatching or birth.

The objection has often been raised by the less thoughtful critics of the evolution theory that the principles of selection and adaptation cannot be of much importance after all, since we see many cases where adaptations fail to work and where selection fails to eliminate such variations. A little more insight into the problem would indicate that, after all, any adaptation only needs to work sufficiently to be of benefit to the species *as a whole*, and not necessarily to all individuals. An adaptation is merely an adjustment to a certain condition of life, and if the condition is changed, naturally the adaptation does not exist; that is to say, the particular reason for the existence of a particular structure, process or instinct, does not obtain and therefore the organism is not adapted any longer. Undoubtedly the reason why it is so difficult to keep many wild animals in confinement, or why they often will not reproduce in captivity, is because we cannot supply the conditions for which they are adapted. A single adaptation is not a master key, it will unlock only one particular gate barring the pathway to existence, and if that gate is replaced by another, that key is useless, but it may not be dangerous to carry it.

There are, to be sure, many examples of imperfect adaptation to be found on every hand and the biologist has not failed to take them into account. The case should perhaps be stated something like this: Successful organisms, by which we mean all organisms that continue to exist, are fitted to meet in a satisfactory manner, the ordinary conditions of their natural environment. But the environment is always more or less variable and the adjustment can therefore seldom be perfect. The organism which is *able to pass the adjustment test with a sufficiently high rating* will get along.

Another misconception along this same line arises from the difficulty which man encounters in attempting to look at the results of evolution from an impartial standpoint. He cannot ordinarily escape from the limits of an anthropocentric evaluation of other organisms, and measures all other creatures by

his own foot-rule. Yet aside from his high nervous organization it would seem that man has little to be proud of. Certainly, in many other systems, he is not to be compared in the perfection of his adaptations with multitudes of other animals. Bertrand Russell has facetiously remarked, "Organic life, we are told, has developed gradually from the protozoon to the philosopher, and this development, we are assured is indubitably an advance. Unfortunately it is the philosopher, not the protozoon, who gives us this assurance, and we can have no security that the impartial outsider would agree with the philosopher's self-complacent assumption."

Some one has referred to the results of selection as "the survival of the adapted," and adaptation means merely the ability to meet the conditions of existence in one way or another. All organisms that continue to exist, must therefore be adapted, and the supposedly lower organization of the protozoan may be just as effective as the more complex structure of the mammal. If the only proof of fitness is continued existence, then the Foraminifera, which have had a long and continuous career from the Cambrian period, at least, are far better organisms than were the Dinosaurs, which lasted only through a few millions of years in the Mesozoic and found continued existence impossible. Man, who has been on the earth only a mere half million years or so, has scarcely been given a fair trial to prove his fitness, and the probabilities are that the Foraminifera will continue to flourish long after man has definitely proved his inability to cope with changing conditions. We should, therefore, in justice to our logic, define carefully what we mean by "higher," for higher specialization does not imply higher adaptability.

A mistaken notion of evolution which has caused great concern to the uninitiated is that it is a theory about the origin of man from a monkey. Just why this idea should be so repellent to a large class of people is difficult to see, for after all monkeys are very respectable in comparison with some humans and, furthermore, they are very high in the scale of animal organization. We will all agree that they are incomparably higher than the "dust of the earth," which many persons seem to prefer for their ancestral stock.

But, of course, in thus speaking of the origin of man, no evolutionist has the modern anthropoid ape in mind any more

than he has the modern man. Both are the evolutionary products of a common stock and have taken different directions, different lines of development. Their relationship lies through a common type of remote ancestor. To approach that relationship, one must go back to more primitive Primates, just as to find connecting links between the Primates and Carnivora one must go still farther back to more primitive mammals.

The nature of the "missing link" has exercised the mind of the non-biological world very greatly, because of an erroneous idea of what constitutes a missing link. As far as I am aware this is always popularly applied to the evolution of man and the usual opinion is that there should be found some intermediate form between man and the nearest anthropoid ape, or, because the general public is not informed or discerning in these matters, between man and a monkey. But no biologist would ever expect to find such a connecting link, for none could exist. Man and the apes are contemporaries and so it is impossible that one should descend or ascend from the other. As well might one expect to find the missing link between contemporary horses and tapirs, though both are descended from the same group of primitive ungulate mammals. What we do expect to find and what, in fact, we do find as we go back in time is that we unearth simpler and more primitive types of man until we come to a brain only two-thirds of its present size, a prognathous jaw, less erect posture, etc., and if we carry this far enough we will come to the generalized Primate stock. If we trace out the ancestry of the apes we will run back in a converging series to the same place. The only sort of a connection existing between man and the apes is that of origin from a similar source.

There is also a mistaken notion that evolution fails to account for the origin of the mind of man. But the modern psychologist and the student of animal behavior are agreed that there is no necessity for assuming any break in the continuity of the series of phenomena in the evolution of mind. The origin of mind is indissolubly linked up with the nature of protoplasm, in its automatic movements, tropisms and reactions. If we begin back as far as the protozoa, we may quote the statement of Jennings that even the Amoeba "behaves as if it had a mind of its own." From the indefinite condition of automatism, irritability and conductivity, exhibited by the

lowest animals, we arrive by gradual steps through the better and better organization of a nervous system to a definite brain and the improvement of this organ through various stages in the vertebrates up to man, without a break. Parallel with this we see the development of reflex action, experimental behavior, instinct and learning, to intelligent behavior, inference and rational purpose.

The evolution theory has been before the world in a concrete form for more than sixty years and all scientific men, or those capable of forming a worth-while opinion, have been agreed on it almost without exception ever since the convincing statement of the case by Charles Darwin. Scientific men have generally shown themselves to be capable of forming sane opinions in their own field, but the general public still finds it a difficult matter to accept the word of the scientist, especially when scientific fact seems opposed to some long-standing belief, or common uncritically-judged experience. After nearly 400 years following the announcement of the Copernican theory, a fair share of people still believe the world to be flat, because all they can see of it looks that way. Many more still believe in witch-craft or the influence of evil spirits, and a still larger percentage hold firmly to the moon as a causative agent in the growth of crops, the curing of meat, etc., etc.

After having written the above paragraph the writer came across the following in the "Century Magazine" for February (1922) in an article on "The American Gypsy," by K. Bercovici: "The study of folk-lore * * * has demonstrated that a certain stratum of the population is never reached by the civilization of any given period. There are as many people today who believe in witch-craft and black magic as there were 500 years ago; as many people who go to fortune tellers to have them read the cards, the palms, or tell the future as seen in the bottom of an emptied coffee cup."

In the field of medicine, notwithstanding the advance of science, the general public is as gullible as ever, in the matter of cure-alls, elixirs and nostrums, advertised to heal all "the ills that flesh is heir to." A recent widely distributed advertisement of Dr. Morse's Indian Root Pills states for the benefit of the public that "Malaria is due to a poisonous miasma, which arising from the low swampy lands, becomes assimilated

with the atmosphere," etc., while every scientific man has known for the past 25 years that it can be distributed only through the bite of an *Anopheles* mosquito.

There is scarcely a newspaper that does not occasionally carry an advertisement of an astrologer, a crystal gazer, a clairvoyant, or other similar kind of fakir, while the number of people who still consult the medical almanac for the signs of the zodiac and the changes of the moon is very large, even in the most enlightened countries. The traditional superstitions of the primitive civilization of our forefathers still hold sway in the minds of multitudes in spite of the advancement of the few.

This is easily understood in the uneducated and in that portion of the public whose intelligence rating is much below the average, for such people either have no capacity for much understanding, or no knowledge on which to base anything but an unscientific belief—and when you come to that kind of belief it is as easy to believe one thing as another, especially if you are not particular as to the basis for it. There is a line in an old hymn which runs to the effect that "blind unbelief is sure to err." It would have been equally true had it stated that blind belief is sure to err. It is the blindness in either case that results in the error. "Belief, in the scientific sense of the word," says Huxley, "is a serious matter, and needs strong foundations."

When we come to the educated portion of the public we have some right to expect more discrimination and less general credulity. We have a right to expect that they will refrain from attempts to discredit the work of capable scientists on the basis that it controverts some already established belief. An educated man should at least be able to draw the line between what he knows and what he doesn't know and not attempt to pass judgment on matters outside of his field of training. The educated man without scientific training has no more basis for forming a proper judgment of the Law of Evolution than of the Einstein Theory of Relativity.

I have said that *no scientist doubts the broad fact of evolution* in the organic and inorganic worlds, but it is equally true that in the minds of many of the unscientific, there still remains not only a doubt, but a positive conviction that evolution is merely a vague guess of the scientist and that it is not necessary

to place any reliance on his views. If the question as to the truth of evolution were to be put to a public vote today, I have little doubt that the scientists would be overwhelmingly voted down.

The newspapers still mistake scientific discussions as to the *method* of evolution for doubts as to the *fact* of evolution and often herald this error in glaring headlines, such as "Great Scientist Disputes Darwinian Theory," "Evolution Theory Disproved," etc., etc. This happened no later than last winter following Prof. Bateson's address before the American Association for the Advancement of Science at Toronto. At the close of his address, Bateson said, "Let us then proclaim in precise and unmistakable language that our faith in evolution is unshaken. * * * Our doubts are not as to the reality or truth of evolution, but as to the origin of species, a technical, almost domestic problem. Any day that mystery may be solved." Though the greatest pains were taken to insure that no mistakes should creep into the subject matter presented to the newspapers for publication, the headliner got in his deadly work uncensored, with the result that the next morning's papers carried headlines announcing the unwarranted assertion that this famous British scientist disputed the fact of evolution.

It is quite apparent that the mass of the reading public are unable to distinguish the difference between fact and method in this field of thought. The campaign against evolution just now being waged by a certain notorious speaker is a case in point. When a man who is very evidently unskilled in the handling of scientific data, unfamiliar with the details of the subject, and solely by an appeal to the emotions through his oratorical presentation, can obtain a wide hearing throughout the country and can even influence a state legislature to consider measures for preventing the teaching of evolution, we must admit that the idea has not yet been fully accepted by many so-called educated people.

The editor of "The Congregationalist," (March 16, 1922, p. 326), however, wisely points out that "Addresses such as that which Mr. Bryan delivered in Philadelphia will do very little to affect the course of science, but we think they are calculated to do irreparable harm to religion." And again, "When one realizes the patience, care and courage with which the sincere scientist pursues his quest of truth, there is some-

thing anomalous in the effort to dominate that field by the superficialities of platform oratory."

Professors Henry Fairfield Osborn and Edwin Grant Conklin have also recently replied, through the "New York Times" of March 5, to an article by Mr. Bryan in an earlier number of the same paper. Osborn points out that "evolution takes its place with the gravitation law of Newton." Conklin comments on Bryan's attempt "to establish an inquisition for the trial of science at the bar of theology," and grows facetious over his proposition "to repeal a law of nature by a law of Kentucky."

Mr. Edward M. Kindle, of the Canadian Geological Survey, writes in a recent number of "Science," "A Don Quixote of Mr. Bryan's calibre only appears once or twice in a century and the opportunity to study in cold print the celebrated Nebraskan's proposal to resurrect the 'special creation of species' myth must be appreciated by our scientific brethren who are interested in studying the mysterious ways in which the human mind works when it approaches subjects unfamiliar to it."

It might be added that the English churchmen knew enough to quit fifty years ago when the proof of evolution was demonstrated to them. The modern opponents of the theory have not a single idea at their disposal that was not worn threadbare and proved useless a half century ago, while the facts supporting the theory have accumulated continuously and voluminously. The more enlightened churchmen the world over, long ago accepted evolution as one of the great fundamental truths, leaving only the ignorant and prejudiced among them to butt their heads against the wall of scientific evidence.

Why then, with this mass of evidence which is so clear to the mind trained in the formation of scientific conclusions, has not the general public been more ready to accept these conclusions? Has the public no faith in the findings of the trained scientist? It would seem so, not only in this matter, but in many others. Who is to blame for this condition of affairs? I fear that the scientists themselves are considerably at fault for not making more effort to place their discoveries before the public in such form that they can be "understanded of the people." Scientists have proved to be very poor

propagandists. The facts and discoveries of science are so interesting to them that they go from one research to another without attempting to make clear to others what they have accomplished. If investigators are constitutionally unable to make their meaning clear to the reading public, then we need a group of interpreters who will make it their purpose in life to investigate the investigators and make known the truths of science to the masses of people who may be able to understand, if the facts are written in their language.

Just where does the evolution theory stand today in the minds of scientific men engaged on problems connected with this field of knowledge.

1. That there has been a cosmic evolution, no one familiar with the facts can doubt, though we may still be unsatisfied as to the truth of the nebular hypothesis of Laplace or the aggregation theory of Chamberlain as they concern the formation of the earth.

2. That there has been evolution, in the form of progressive changes of the earth itself, no one capable of forming a proper judgment can doubt, though we may still question the number of aeons it has taken to round the surface of the earth into its present form, and the exact mode of formation of certain rocks and strata may still puzzle us somewhat.

3. That there has been an evolution of organic life on the earth no one familiar with the accumulated data will doubt for a moment. The facts are so patent that one does not even have to possess a very logical mind to be convinced of the truth. The succession of animals and plants from lower to higher forms in past time, as shown by paleontological studies, is as clear and straightforward as any story which research has ever brought to light. This, coupled with the facts of embryology and comparative anatomy, yields a truth which no unprejudiced man can deny. For any one to do so merely proclaims his narrow-mindedness and prejudice and classes him among those of the last degree of blindness who "will not see."

4. That modern man himself is just as patently a product of evolution is clear to anyone familiar with the findings of paleontological anthropology, even if we do not consider the evidence from embryology and comparative anatomy. Our knowledge of fossil man takes us back through several extinct

human species—Neanderthal, Heidelberg, Piltdown, Foxhall and Trinil Man. These extend successively farther and farther back, through the different glacial periods to the later Pliocene, over time variously reckoned in years around 500,000. Through this succession of human species we can trace the gradual development of the cranial capacity to an increase of at least 50%; the retraction of the face from a prognathous to an orthognathous condition, the development of a chin, making possible the free use of the tongue in speech; the completion of the erect posture, and various other features by which man has become physically differentiated from his nearest animal kin. Along with this physical progress we can trace, *pari passu*, the evolution of his civilization.

Granted that we do not yet know all the processes by which these changes in man have come about, the fact that they have come to pass is so evident that only the ignorant, or he who willfully ignores the truth for his own ends, will attempt to dispute the fact. Place what interpretation on it you wish, the fact remains. I hold no quarrel with the man who accepts the fact and interprets it as the method of a supreme being for working out his eternal plan, or, as John Fiske said, "God's way of doing things."

Only we must not let our religious *beliefs* get the better of our common sense appreciation of *facts* in this or any other matter. There is no thing as sacred as truth, in whatever form it comes, and if it interferes even with a long-established belief, then it is time that the basis for that belief is looked into.

We have seen that the evidence of evolution does not rest on guesses or interpretation, but on facts, and not in one field only, but that astronomy, physics, chemistry, geology and all the biological sciences tell the same story in the same way, that of uniformity, continuity and progressive changes.

Gradually, of course, this natural law will receive general acceptance among the reading and thinking public. In the meantime, whenever some misinformed or bigoted egotist displays his ignorance of scientific matters, there are two things which we may do; either we may attack his mis-statements and set the unscientific public in the right through the press, or we may follow the plan adopted by the man who was kicked by a mule, and just "consider the source."

DYNAMICS OF THE LITHOSPHERE.*

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INTRODUCTION.

It is a characteristic of the human mind that the things least easily understood are the things most desirable to know; and this insatiate curiosity frequently devises means to unlock the hidden and to overcome the impossible. It has been in large measure this psychological impetus that has prompted studies dealing with the unattainable central structure of our globe, and with the slow, invisible adjustments and responses, to which terrestrial matter is subject.

By lithosphere is meant the solid or rock part of the earth, not water and air, but probably all the rest from center to circumference. In order to gain an accurate impression of the adjustments taking place in the earth's outer part and of its physical condition, it is necessary to consider the whole problem of the interior of the earth. All evidence relating to the physical condition of the interior of the earth or to the adjustments of the earth's substance will, therefore, be first drawn together without statement of its reference to the problem; then conclusions will be drawn from the facts. In this way the influence of theories which may or may not be true will be avoided to some extent.

Our thesis is that essentially all the problems of the dynamics of the lithosphere resolve themselves into the problem of adjustment of strains and stresses in the structures and materials of the earth, adjustment to the equilibrium form of the earth, through the force of gravity, involving diastrophism, vulcanism, and gradation.

THE ASTRONOMICAL AND PHYSICAL DATA.

Astronomy has furnished the geologist three lines of argument pertaining to the physical condition of the earth's substance: These are precession and nutation, variation of latitude, the shape of the earth.

Precession.—Because the axis of the earth describes a cone in its motions, tracing a circle about the pole of the ecliptic, the equator, which preserves about the same inclination to the ecliptic, moves so that its intersections with the ecliptic pass in a retrograde direction opposite to the earth. This motion is termed the precession of the equinoxes.[1] Precession

[1]Encyclopoedia Britannica.

is caused by the fact that the attractions of the sun and moon are not a single force acting through the earth's center of gravity. Since the variation is due to the attraction of forces which are estimatable, methods of calculation are possible by which the mass of the earth may be revealed.

Nutation[2] is a vibratory motion of the earth's axis, producing a wavy circle of precession, due to the unequal attraction of the moon on the equatorial ring of the earth. This, too, affords another method or means of calculating the earth's mass.

Variation of latitude[3–5] is caused by a shifting of the axis of rotation within the sphere so that its polar extremities wander in a circle of about fifteen (15) meters in diameter. By computation it should have a period of 305 days; but Chandler, from a great mass of data, discovered an actual period of 427 days.[4] Such a retardation can be due only to a shifting of the equatorial bulge, by the lagging adjustment of which retardation of the period is effected. Now since adjustment in the rocks is slow and incomplete, a tide must be set up in response to the strains developed by the shifting of the axis, because water is very adaptable to external force. Dr. Bakheyzer and Mr. Christie have independently investigated this problem of tides and both conclude that there is a tidal variation with about a 430-day period.

The shape of the earth [6–7] has been a subject of long and extensive study into which we do not need to enter. Suffice it to say that the shape has been determined to be very nearly an ellipsoid of revolution, showing that the earth's substance is sufficiently plastic to be nearly perfectly adjustable to rotational forces. The superficial exceptions will be discussed later.

Schweyder[8] has recently determined the nutation period as 432.8 days.

The physical data throwing light on the condition and responsiveness of the earth's substance are varied and extensive.

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[2]Encyclopoedia Britannica.
[3]Ibid.
[4]Darwin: Tides, Chap. xv.
[5]Chamberlain, Reed, Hayford Schlesinger, Smithsonian Rpt., 1916.
[6]Encyclopoedia Britannica.
[7]Poynting & Thompson: Text Book on Physics.
[8]Schweyder W. Naturwissenschaften, 1917, Potsdam, Germany, pt. 38. Quoted from Jour. Geol. 1921, v. 29, p. 396.

The plumb line[9—10] has been used near mountains to estimate the mass of the earth. The deflection from the vertical, due to the attraction of the mountain, is measured. The mass of the mountain is then calculated, and from these data the mass of the earth is calculated. By this method Maskelyne, in 1775, secured a mean density of 5. and James, in 1854, obtained 5.32.

The pendulum[9—10] was first used by Bouguer. The number of swings of the pendulum at the surface are compared with the number on a mountain, and the comparative attraction worked out. Carlini, 1821, obtained a mean density of the earth of 4.84; Airy, 1854, obtained 6.57; Pechman, 1865, 6.13; Mendenhall, 1880, 5.77; Sterneck, 1883, 4.77, and in 1885, 6.77; Preston, 1892, 5.13.

The Cavendish method.—In this experiment two small balls are placed at opposite ends of a wire and their movement measured when attracted by a large ball of known mass. A comparison is then made between the attraction of the earth and the attraction of the ball. Cavendish, in 1798, found 5.45 to be the mean density of the earth; Bailey, 1843, secured 5.67; Reide, 1852, 5.58; Corme and Baille, 1878, 5.5; Wilsing, 1889, 5.56; Preston, Bays and Braun, in 1895 and 1896, all secured 5.53; in 1902, Burgess obtained 5.55.

The chemical balance has been successfully used by determining the attraction of a known mass placed above or below the scale, and comparing with mass of earth. By this method Poynting, 1891, secured a specific gravity of the earth of 5.49; and Richarz and Krigar Menzel in 1898 obtained 5.51.

Tides.—The evidence from tides is very simple yet very conclusive. If the earth is liquid with a crust or lacking in rigidity, then the entire crust will yield for a tide; but if it is rigid—as rigid as steel—there will be some rock tide, but the tidal force will be largely consumed in raising tides in the more responsive hydrosphere. Calculations on the height of tides by Darwin[11] and others shows that the tides are exactly what are to be expected on an earth of the rigidity of steel. Prof. Millikan has, however, measured tides in the rocks.

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[9]New International Encyclopoedia.
[10]Osmond Fisher: Physics of Earth's Crust.
[11]Darwin: Tides.

Support of load.—Physicists have pointed out that a liquid interior would not support continental masses rising 3,600 to 5,400[12] meters above the ocean floor. But probably this argument is of little value when isostatic measurements have shown them to be of lower specific gravity.

Relative density of solidified and molton rocks[13] is such that a crust could not permanently form on a molten sphere in which convection currents are possible, since solidified rocks are denser than molten rocks.

Behavior of rocks under pressure.—It is a well-known law of physics that the melting point increases or rises with pressure[14]. Barus found the rise of the melting point of diabase to increase directly as the pressure. This would give a melting point of 76,000° C. at the center of the earth. Under such pressures as exist at the center of the earth, many physicists claim, it would be impossible to obtain molten rocks, because such an adjustment would be necessary as gave the least space, and it is certain that crystalline rocks occupy less space than molten rocks do. An increment of temperature increase amounting to about 1° C. for every 18 meters of descent has been found. Assuming the radius to be 6,268 km., this would give a temperature of 347,600° C. at the center, which is more than four times the melting point of diabase under the pressures assumed at the center. But it is unlikely that such a rate of increase can be supposed. Deeper borings seem to indicate a lessening rate, and a point may be attained, perhaps comparatively near the surface, where temperature ceases to rise. It is not our problem to account for the heat. It may be due to the mechanical work done, to radio-activity, to chemical action, or compression, or all together.

Another line of experiment giving some possible light on the condition of the interior of the earth is furnished by those investigations dealing with the crushing and flowage of rock. Van Hise[15] states that more than 1,700 kilograms of pressure per square centimeter are necessary to crush granite.

Fisher[16] has estimated 3,000,000 atmospheres of pressure at the earth's center.

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[12]Chamberlin & Salisbury, Text II, 7.
[13]Fisher: Physics of Earth's Crust.
[14]Chamberlin and Salisbury: Textbook in Geology II, 7.
[15]Van Hise: Principles of Pre-Cambrian Geol., U. S. G. S., 16th Annual Report.
[16]Fisher: Physics of Earth's Crust.

Hayford[17] and Bowie give the crushing strength of granite as about 1,425 kilograms per square centimeter, which place the zone of no cavities at about 8 kilometers. Van Hise, working on this problem, using the crushing point of rock as 1,700 kilograms per square centimeter, obtained adepth of 10,000–12,000 meters.

GEOLOGIC AND SEISMOGRAPHIC DATA.

Geologic Climates.—It was the problem of variability of geologic climate that caused the final overthrow of the Laplacian hypothesis. There have been in geologic history seven periods of climatic change.[18] Four of these have been glacial periods: the first two, early and late proterozoic, are well down the geologic column, and indicate a cold climate early in geologic history not at all reconcilable with a cooling globe, which is implied by a molten interior. The other periods of climatic change are the Silurian, Permian, Triassic, Cretaceous, Eocene, and Pleistocene, of which the Permian and Pleistocene are glacial.

"Original Crust".—The great granite embossments of Scandinavia, Canada, and other countries, formerly believed to be the exposed surface of the original crust, have been shown to be but intrusions in older sedimentary rocks, or in some cases greatly altered sediments.[19] The fact that there are now no known exposures of the original crust, certainly none that could have served as an original source of the sedimentary rocks—such a lack of original feeding grounds, certainly militated against the idea of an original crust at all.

It is obvious, too, that if our earth has been built up from planetesimals which have been gathered in upon a nucleus there will be no uniform gradation of material in any direction, nor any zoning into concentric layers so that any one layer will be essentially homogeneous as to density, melting point and composition. Presumably this heterogenity is not as great as it was ages ago when the infall of planetesimals was more frequent and when the larger part of the accretionary accumulation was not so far remote.

[17]Hayford and Bowie: Spec. Rept., U. S. C. & G. S.
[18]Pirsson and Schuchert: Text Book of Geol.
[19]Chamberlin, T. C., 1916, Smithsonian Rpt.

This theory leaves no place for a "crust" conception as in the La Placian theory. But it does make place for enough variation in the composition and fusibility of earth materials even at the same depth that given a certain temperature in a zone only parts will become fluid. Fluid parts might tend to rise toward the surface. Parts remaining solid must then collapse leaving a solid zone. This would tend to produce a zonal arrangement of the earth materials. That such a gigantic banding is not perfected is shown by the persistence of volcanic intrusion and probably by diastrophism.

Geographic Distribution of Igneous Intrusion.—A third line of evidence is that afforded by the extent and distribution of igneous intrusion.[17] Were a molten globe surrounded by a thin crust, strains and stresses within the sphere would be in large measure relieved by igneous extrusion. The extent of igneous extrusion does not seem in any way commensurate with the stresses that are found. The localization of its geographic extension to certain well-defined areas would hardly be expected of lavas extruded from a molten interior; and it is therefore unlikely that igneous phenomena have more than a local and perhaps rather shallow source.

Seismographic Records.—The invention of the seismograph, by which earth tremors are automatically recorded with the exact time of their occurrence, has contributed much to the solution of our problem. From every seismic focus there proceed three sets of waves: those that travel along the surface and those that pass through the earth, of which there are two kinds—compressional and distortional.[20] Those which pass through the interior increase in velocity with depth below the surface, and increase more rapidly than the density, showing that the earth is rigid, and that its rigidity increases toward the center. Waves have never been recorded along a diameter, but as far as they have passed into the earth's interior, geologists may be sure that the earth is solid, for transverse waves cannot exist in a liquid and they are always recorded with the longitudinal (compressional) waves.

These records have made it possible to get at the depth of the seismic focus. In the case of the Neapolitan earthquake $10\frac{1}{2}$ kilometers was the calculated depth.[21] The mean depth

[20] Interior of Earth: Oldham, Q. J., G. S. Lon., v. 62, 1906.
[21] Davidson: Earthquakes.

of the focus in the Ischian disturbance was about 500 meters., and of the Andalusian of 1884, 12½ kilometers; the Charleston showed a depth of seven and one-third kilometers, and the Rivera 18 kilometers. The San Francisco earthquake showed a depth of disturbance of about 24 kilometers.

Many attempts have been made to measure the velocity of the waves at the surface, but with such varying results as to indicate inaccuracy of method or data, or perhaps to some degree to indicate varying density.

THE DATA OF ISOSTASY.[22]

Isostasy is the theory that any given column of rock taken from the center of the earth to the surface will have the same mass as any other column of the same cross-sectional dimensions. But as density of rocks varies the height of the column will vary. The inequality of density, however, is found only in the part of the column near the surface, and the difference in the length of the column is due to difference of density in the upper 122 kilometers (77 miles) of the column. The adjustment of material toward this balance under the force of gravity is called "isostatic adjustment." Defective density resulting in a taller column and excessive density causing oceanic basins, that is, a shorter column, constitute "isostatic compensation."

The density of any given column is calculated from the vertical component of the forces operative on a swinging pendulum or the forces deflecting a plumb-bob. Corrections must be made for the effect of topography. The pendulum method has been found most satisfactory and is generally used.

The scheme followed by the U. S. Coast and Geodetic Survey is as follows: eighty-nine stations were selected in the United States, and sixteen over the rest of the world. At these stations pendulum apparatus is set up, and the vertical component of gravity worked out. In order to correct for topography the entire earth is divided into 317 compartments, and the effect of each compartment computed. These corrections are applied to obtain the actual value of gravity due to density below the station. Next the value of gravity at the station is computed, a mean surface density of 2.67 being

[22]Special Rpt. No. 10, U. S. C. & G. S., pp. 6, 7, 108.

assumed. The computed density subtracted from the observed density gives an anomaly which is approximately 1 part error and 4 parts departure in density from the normal. When observed density is less than the computed density the anomaly is negative. The anomalies thus secured bear no relation to topography.

The following conclusions have been pointed out:

1. The anomalies bear no definite relation to loading and unloading.
2. The United States is in isostatic adjustment with a mean departure of 171 m. of rock with 2.67 density.
3. A relation to geologic formation exists by which the older formations have a positive anomaly.
4. Intrusive and effusive rocks give an anomaly very near to complete and perfect isostatic compensation.

DATA OF DIASTROPHISM.[23]

It is hardly necessary to review here the evidence of actual crustal movement. One might, however, mention a few of the most important, such as mountain making, folding, faulting, tilting of lakes, elevated or depressed shorelines with their familiar accompanying physiographic features, actual measurement of movements, and submergence of oceanic islands. There was much change of level in and after the Pleistocene in the Great Lakes region, in Scotland, and in Scandinavia.[24]

The most noticeable fact of diastrophism is that it is most intense in regions of thick sedimentation, that is, where geosynclines have been filled. The Appalachian geosyncline presents 12,000 meters of sediment; others have nearly as great thickness; 10,000 meters are found in the Laramide structure; 3,000 meters of Eocene rocks were deposited in the Rocky Mountain geosyncline. The Alps present 15,000 meters of sediment.

Experiments reveal an expansive coefficient of 1 cm. to 19.2 meters for every rise of 100° C. in average rock. In the case of the Appalachians, 800° at the bottom of the geosyncline would have given 1650 meters expansion. In Pennsylvania

[23]The most satisfactory discussion of the facts and theories of this problem is found in Dana's Manual of Geology, fourth edition.

[24]W. B. Wright: Quaternary Ice Age, 1914, pp. 406-426.

the actual shortening lies between 70 and 140 km., thoroughly beyond the power of increased temperature to create.

Intense normal faulting follows intense folding almost without exception.

Extensive faulting is usually apparently confined to regions of thick sedimentation. It is difficult, however, to detect faults in igneous rocks, also in some metamorphics. This may help to explain the apparent distribution of faults.

THE CENTROSPHERE.

The term "centrosphere" may be used to include that portion of the earth throughout which rocks are adjustable to stress through flowage, and in which cavities and fractures do not exist. It would thus be within the so-called "crust" or zone of fracture. The seismographic evidence shows two very important things in regard to this interior; first that it is solid, because it everywhere transmits transverse waves, which cannot pass through a liquid—this evidence is conclusive; secondly, that it is increasingly dense toward the center, attaining a specific gravity of 6 at .4 radius distance from the center—evidence calculated from the rate of wave transmission through the interior. At this rate of progression a density of 8.22 would be attained at the center, assuming the surface density to be 2.67. It is unlikely that this progression holds beyond this depth, because the mean density of 5.6 requires a central density of 11. Down to a depth of .6 radius the increased density is thought to be only that due to increased pressure; below this depth the earthquake researches of Oldham[27] may throw some light on the problem. He found that at a distance of approximately of 130 degrees from the point of origin, distortional waves were suddenly broken off to be continued beyond this distance approximately 11 minutes later. Just what inferences should be drawn from this, it is not possible to say, except that it is altogether likely that there exists a central core of about .4 radius extent from the center, required by other facts to have a density very high, probably between 8 and 11, and if dense to have a refraction of at least 2.

Some conclusions may be drawn as to rock flowage through the centrosphere. Granite has a crushing strength of 1,425

kgm. per cm.[25] while the pressure at the center of the earth is estimated at approximately 3,380,000 kgm. per sq. cm.[26] There can be no question but that rocks under these conditions will readily adjust to stress or strain. Yet Oldham[27] calculates that waves emerging at a point 90 degrees distant from their origin have passed through material having 12 times the resistance of granite and 15 times its rigidity. He adds: "Probably this is only what can be traced to increased pressure."

THE CRUST.

The term "crust" is used to describe that portion of the earth which lies above the level of compensation, and consequently includes all fractures, cavities, and most of the adjustment of the earth's solid substance. Crust and centrosphere constitute the lithosphere.

Depth.—Isostatic investigations have placed the compensation surface—by which is meant the surface at which compensation is complete—at 122 kilometers, which seems by results obtained to be near the truth; from other evidence the allowance seems ample. Van Hise, assuming the crushing strength of rocks to be 1,700 kilograms per square centimeter, surface density to be 2.7, and cavities to be supported by hydrostatic pressure, found that no cavities or crevasses would be possible at a depth of 10,000–12,000 meters. Fracture, however, might occur at this depth. Seismographic evidence would bear out this conclusion. Most seismic foci lie above 17 kilometers of depth. In the case of the Neapolitan earthquake, the deepest estimate fell near 39 kilometers, although the mean depth fell at 10½ kilometers. It is unlikely that this estimate is correct, because of the imperfect methods of calculation and the unknown density of the rocks through which the waves passed. Assuming it to be correct, it is still a very shallow phenomenon and well within the limits of 122 kilometers. Oldham[28] believes the more or less heterogeneous material may not be more than a score of miles thick.

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[25]Special Rpt. No. 10, U. S. C. & G. Survey, p. 111.
[26]Fisher, O.: Physics of the Earth's Crust.
[27]Oldham: Some Conclusions as to the Interior of the Earth. Q. J. Geol. Soc. Lond. (1906), V. 62, p. 456-75; Vol. 63, pp. 344-350.
[28]Oldham, R. D., loc. cit.

Density.—Surface density by estimation of its known components cannot be far from 2.67. A gradual increase with pressure due to recoalescence, and compression and inclusion of gases, due also to the closing of cavities, might be expected. This gradual increase is supported by seismic investigations.

This topic and many others have been elucidated by the recent papers of the Chamberlins in Jour. of Geol. Vol. 29–30.

Adjustability.—The most important result of our studies is the establishment of the fact that adjustment throughout the crust to external forces or to internal stresses is almost perfect. We have seen that the variation of latitude occurs because the equatorial bulge persists in shifting with the shift of axis. But back of this wehave evidence of adjustmentin the shape ofthe earth itself, which is very nearly the true form of an ellipsoid of revolution. That it varies at all from this form is evidence, equally good, perhaps better, of its plasticity. Its apparent inequalities are the result of its adjustment of heterogeneous density to the equilibrium of the ellipsoid of revolution. (See note.) We believe that the whole problem of volcanism, mountain-making, continent and ocean-basin formations, and all diastrophism are but phases of the problem of maintaining adjustment to this form of the earth. That this adjustment is nearly perfect, having an average departure of only 171 meters of rock of 2.67 specific gravity in the United States, has been proven beyond the stage of hypothesis. Even the maximum anomaly or lack of adjustment found in the United States corresponded to a stratum only 1,000 meters thick or a deficiency of pressure of 278 kilograms per square cm. or less than one-fifth the crushing strength of granite. This is an extreme and unusual anomaly. That this adjustment has been demonstrated in a broad way in regard to ocean basins and continental masses is beyond doubt.

The fact that there is essentially no relation to loading and unloading in the gravity anomalies would indicate rather rigid adjustment. The quick submergence of volcanic islands having a positive anomaly is also good evidence. There is no doubt that the area of deficient density through Nevada, part of Colorado, Arizona, and Southern California is in a stage of uplift.

Note—By equilibrium is meant an equilibrium of density, essentially what is implied in the term "isostasy."

Volcanism.[29]—The evidence of geographic distribution, extent of extrusion, and differentiation of magmas indicates that volcanism is a local phenomenon. Seismic evidence clinches the argument.[30] Distortional waves will not pass through a liquid, yet they pass with perfect freedom through any part of the crust at which observations have been made. There cannot, therefore, be any considerable lava lakes beneath the earth's surface. Isostatic investigations throw an illuminating line of evidence on the problem. Igneous intrusions and extrusions of all rocks are almost perfectly compensated.[31] It would seem then that volcanism is simply one method of quick adjustment to the equilibrium figure. It would be found in places of defective density where decreased pressure produces liquefaction in the form of a vesicle which rises to the surface, and in one way or another is ejected by force. Most of the vesicles stop before they reach the surface. Denser material is thereby added to, or replaces, lighter material bringing about isostatic compensation. The method would appear to be thoroughly delicate to reach isostatic adjustment so perfectly. One would expect the process once set off to continue this inertia beyond the point of perfect compensation. This is known to occur frequently in the case of volcanic islands that are thrown up with a positive anomaly, but which soon sink into a state of equilibrium.

Mountain Making.—This is another process resulting from the tendency of the crustal substance to maintain a state of equilibrium in reference to the figure of the earth through the force of gravity. The process is this: Marine sediments are laid down in a geosyncline, or along the edge of a continent. To maintain adjustment subsidence takes place until great depths of sediments are found. Isostatic adjustment is practically perfect throughout the process. The sediments thus laid down have, of course, a lesser density than the sediments or rocks on either side. There is, therefore, an imperfect horizontal adjustment to the bottom of the geosyncline. Now, as the sediments are forced downward temperature rises. Probably 800 degrees is attained at the bottom of the geosyncline, and since it contains rocks with more or less water inclusion, the steam developed, or at least the heated water when pressure is too great

[29]Iddings: Problem of Volcanism.
[30]Smithsonian Rpt. (1916), The Earth's Figure, etc.
[31]Special Rpt. No. 10, U. S. C. & G. Survey.

for steam, weakens the rocks, and the expansion caused by increased temperature, amounting to 1 cm. to every 19.2 meters for every 100 degrees C. rise of temperature, causes a slight disturbance which is carried on by the pressure from the sides; erosion and deepening of the geosyncline tend to maintain isostatic adjustment throughout the process. Now inertia may carry the process beyond isostatic adjustment; certainly the rock thus thrown up cools to some extent. Both things may occur; at least there is always a period of normal faulting[32] succeeding a period of folding which might be caused by these factors. The mountain making process may be aided by lateral pressure developed by crustal expansion due to rising temperature of the crust. This, however, is mere supposition, and perhaps unsupported by geologic evidence.

Faulting is another process through which equilibrium is maintained. It differs from mountain making largely in that rock flowage and bending are predominant there; whereas faulting is the result of adjustment with fracture of the rocks rather than flow. It is not usually associated with the deeper synclines, although it is confined probably to regions of rather deep sedimentations.

Causes of lack of adjustment may be external, such as the tidal influence of the sun or moon, the shifting of the rotational axis, pressure of the atmosphere, increased load due to formation of glaciers, or the accompanying emptying of the seas, great evaporation or excessive precipitation; but probably the great cause of lack of adjustment is the shift of load due to erosion.

Earthquakes, so far as is known, present no opposition to our thesis that all the dynamics of the crust are the result of processes of adjustment of heterogeneous density to the form of the earth through the forces of gravity. The fact that calculations of depth of focus invariably indicate not a point but a plane lying more or less vertical to the surface, and that many earthquakes actually accompany slipping along a fault plane, would indicate that the phenomena of tectonic earthquakes are invariably of this character. The fact that many earthquakes show merely lateral stresses without elevation or depression in no way militates against our general thesis. Lateral stresses

[32]T. M. Reade: Evolution of Earth Structure, p. 137-8.

would be set up in surrounding rocks by elevation or depression at a distance without local diastrophism. The amount of accumulated stress resulting in sudden adjustment by fracture and displacement will depend upon (1) the intensity of the lateral stresses, and (2) the plasticity of the rocks by which strain and stress can be adjusted without fracture.

Continental Creep has not entered into our studies. It is not, however, too much to suppose, since we know the rocks to be highly plastic, that the difference of pressure on the land side and water side of the continental slope will result in creep toward the ocean; the same sort of phenomena that give rise to mountains. Yet if this is true, the whole process maintains isostatic adjustment throughout, for anomalies of gravity nowhere indicate a general excess of gravity along the continental platform, which lack of adjustment would require.

Some Immediate Causes of Adjustments.—While much of the evidence presented in this section on "The Crust" indicates rather rapid adjustment to anomalies, it is true that there would be no anomalies if the adjustment did not lag more or less behind the causes which produce maladjustments. This is only another way of saying that stresses and strains are cumulative, that they may be held by the structures for some time, but that ultimately the earth structure has failed to hold them, as shown by Leith.[33] If the strains are held a longer time and become great, their release causes large and widespread adjustments. If the stresses are frequently released, only smaller and often local adjustments are necessary. When the balance of stress and structural strength is almost struck, but little is necessary to start adjustments. Tides, distant earthquakes, or even changes in atmospheric pressure are believed to be competent to start potential movements.

Deltas furnish a good line of evidence of almost continuous adjustment, for if adjustment did not take place rather rapidly, deltas and other areas of loading would indicate a positive anomaly. A positive anomaly is found at the mouth of the Hudson and through the Chesapeake Bay region. But we know that these areas are in a stage of subsidence, so that adjustment, if not complete, is taking place. On the other hand the delta of the Mississippi shows negative anomaly, due perhaps to the

[33]C. K. Leith, Structural Failure of the Lithosphere, Science, 1921, pp. 195 ff.

tending of physical movements to carry beyond adjustment through inertia.

Continental masses and ocean basins have been demonstrated through isostatic measurements to be in isostatic compensation. This means that the continents and basins must be due to differential density, and that in this large configuration the shape of the crust is still in accordance with our thesis. Earthquake studies have thrown light on this problem also.[34]

CONCLUSION.

We have seen that the phenomena of mountain-making, volcanism, faulting, and earthquakes, together with density differentiations, are due to the processes of adjustment, through gravity of varying mass, to the equilibrium figure of the earth, and that continental creep and sedimentary loading, especially in deltas, though not due to this cause, yet are kept in isostatic adjustment. Our conclusion is therefore as follows: the dynamics of the lithosphere are essentially the processes of adjustment of strains and stresses in the varied structures and materials of the earth, adjustments to the equilibrium form of the earth, through the force of gravity, involving diastrophism, volcanism, and gradation.

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[34]Oldham, R. D., Q. J. G. S. London, Vol. 63, 1907, pp. 344-350.

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SOME BIONOMICS OF ALPHELINUS SEMIFLAVUS (HOWARD)*

Chalcid Parasite of Aphids

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GENERAL CONSIDERATIONS.

Aphelinus semiflavus How. is one of a few species from the genus *Aphelinus*, of the Chalcidoid family Eulophidæ, known to attack aphids. The others are scale parasites. At present there are but seven described species for North America, recorded as aphid feeders; namely, *Aphelinus mali* Hald., *A. nigritus* How., *A. Semiflavus* How., *A. Flaviceps* How., *A. Lapisligni* How., *A. varicornis* Gir., and *A. automatus* Gir. In addition to this number, the writer has recently taken two new species: one from an aphid on potato sprouts in the State Insectary at Whittier, California, and the other from *Sanbornia juniperi* Perg., an aphid on juniper in Pennsylvania. Both are being described by Dr. L. O. Howard.

* Contribution from the Department of Zoology and Entomology, Ohio State University, No. 70.

These parasites, so far as known, are limited to the aphids as hosts, and most, if not all of them, are confined to a few species. *Aphelinus mali* was long considered an exception, appearing many times in the records as a scale parasite, also. However, Dr. Howard,* authority on the group, now believes these records to be in error, and further states that it is probably not only confined to aphids, but is likely restricted to the woolly forms, especially the common *Eriosoma lanigera* Hausm., of the apple, a species often associated with scale insects; a fact which may account for the confusion in the records.

The group, on the whole, are extremely minute and inconspicuous insects, not often met with by the average entomologist. Many of the species are quite rare, even to the specialist on the alert for them. At best they rank secondary to the Braconid subfamily Aphidinini as a factor in the control of aphids; although they have been known (Prof. T. H. Parks†) to play a considerable part in some outbreaks (Toxoptera in Kansas during 1909). For these reasons, they have practically escaped attention from a biological standpoint, and most of them have been known systematically but a few years (since 1908).

With the hope of contributing something to the knowledge of the bionomics, life-history, economic importance, and relationship to the aphid complex in general, work was begun on *Aphelinus semiflavus* in the greenhouse insectary of the Ohio State University, Department of Zoology and Entomology, in the fall of 1920, as part of a thesis for the degree of Master of Science in Entomology. This was continued throughout the winter to the middle of May, 1921; when the thesis was written. After graduation in June, part of a series of parthenogenetic generations of the parasite was taken to Oak Lane, Philadelphia, Pennsylvania, where rearing and study was continued at intervals until the time of this writing, February, 1922.

ACKNOWLEDGMENTS.

The writer here wishes to express appreciation for the kind assistance of Dr. Herbert Osborn, who directed the work with many valuable suggestions and criticisms, and to Dr. R. C.

* Private communication.
† Private communication.

Osburn for suggestions and corrections in manuscript. Many thanks are given to Prof. T. H. Parks for useful suggestions on rearing methods and recording of data; to Dr. C. H. Kennedy for aid in microtechnique and drawing; and to the entire staff of the Department for aid in advice and equipment.

Among those outside the University to whom the writer is especially grateful, are Dr. L. O. Howard, authority on aphis-feeding Aphelinids, who very generously gave of his valuable advice, and assisted greatly in the confirmation of records and determinations; Mr. A. B. Gahan, of the National Museum, for determining the parasites; Mr. T. L. Guyton, of the Pennsylvania Department of Agriculture, for determining the aphids; and Dr. Paul Marchal, director of the Entomological Station, Department of Agriculture, Paris, France, for giving first hand his experience in colonizing *Aphelinus mali* How. in France.

METHODS AND APPARATUS.

Practically all the data included in this paper are from indoor rearing, either in a greenhouse or room. Most of it was carried on in the greenhouse insectary of the Ohio State University, and near a window in room 107 of the Botany and Zoology building. The observations made in Pennsylvania were taken on material grown before an open window in the writer's private room in Oak Lane. That the results thus obtained should vary with outdoor conditions is a fact which must not be overlooked; especially since experience has shown *Aphelinus* to be quite sensitive to slight temperature changes below a certain point.

The temperature in the greenhouse insectary varied from 50 degrees Fahr. on cold winter days, to 100 degrees on warm, sunny days of early fall and late spring. For the greater portion of the time, it remained between 70 and 80 degrees Fahr. The room in the Botany and Zoology Building stayed very close to 70 degrees all the time. No temperature readings were taken for Oak Lane, but here it was very near outdoor temperature during the summer and warm room temperature (70 degrees and above) for the winter.

Light and humidity were not measured.

Those cages which gave the most satisfaction in the matters of light, ventilation, security, and accessibility, were the

standard lantern globe cage used in rearing aphids, and a specially designed celluloid cage. The celluloid cage was found to be far superior to the lantern globe in ventilation and its equal in all the other factors. However, both were used with success throughout the work.

Myzus persicæ Sulz., a common aphid on dock and crucifers, was used for a host in practically all the experiments, although several other species were carried along for the purpose of testing the parasite in other hosts. This aphid proved to be quite satisfactory in every way; since it was the natural preferred host of *Aphelinus semiflavus*, reproduced readily throughout the winter on a number of common plants, and was attacked by practically every other aphid parasite. Dock (*Rumex cripus*, and *R. obtusifolius*) was found to be the best host plant for this aphid, and was also very satisfactory from an experimental standpoint; being easily grown, and having large smooth foliage which greatly facilitated observation and handling.

Parasite-free material was obtained by rearing in tight cages.

In all experiments, a few specimens confined in a small, neat cage gave better and more accurate results than many in a large cage. Too many aphids to start with would multiply so rapidly that they would kill the plant before the experiment could be closed, making it necessary to transfer them, which always resulted in loss of material.

For development studies, a number of parasites were confined with parasite-free aphids for a few hours and then removed. A number of these aphids were dissected at intervals to determine the stages reached by the parasite in a given time. These dissections were made in normal salt solution held in a hollow ground slide under a binocular microscope. Very fine sewing needles mounted in matches served as excellent instruments. When the parasites had killed the aphids, they were removed to gelatin capsules marked with the number of the cage and date of removal. These were then filed in small cardboard boxes, by the month, for further reference, in watching their development from then on. These developments in the capsules were checked by cage rearing and found to coincide. Gelatin capsules were made use of as containers for all the material that was retained for future reference.

IDENTITY AND DESCRIPTION.

Aphelinus semiflavus was first described by Howard ('07) as follows:

Female.—Length 1.08 mm.; expanse 1.87 mm.; greatest width of fore wing 0.3 mm. Antennæ short, excluding scape about the length of face; pedicel long, more than three times as long as wide; funicle joints 1 and 2 in length and width and each slightly less than one-third length of pedicel; joint 3 two-thirds length of pedicel and about as wide as its tip; club slightly swollen, ellipsoidal, and about twice the length of pedicel. Eyes faintly hairy. General color black; thorax smooth, shining, scape and pedicel dusky, flagellum pallid, club becoming somewhat dusky at tip; front and middle femora and all tibiæ somewhat dusky; hind femora straw yellow. Abdomen light yellow shaded around margin with brownish. Wings rather short, otherwise normal.

Male.—Length 0.85 mm.; expanse 1.58 mm.; greatest width of fore wing 0.204 mm. Differs from female in having antennæ nearly uniform brown, scape slightly darker, and in the proportion of third funicle joint and club. Third joint cylindrical, twice as long as pedicel and six times as long as broad; club one-quarter longer than third funicle joint, elongate ovate in shape.

Described from 14 male and female specimens reared by C. P. Gillette, Fort Collins, Colorado, July 15, 19, 1908, from Myzus persicæ, and reared at Washington from the same host sent in by Professor Gillette. The parasitized host turns black.

U. S. N. M. type No. 12,931.

DISTRIBUTION.

Geographical.

There are very few available records on the distribution of *Aphelinus semiflavus*, but these seem to indicate that it is rather wide for the United States, at least. Dr. Howard has kindly furnished the writer with the United States Bureau of Entomology records that he had available, which follow:

Reared from Myzus persicæ Sulz., Fort Collins, Colorado, by C. P. Gillette, July 15, 1908.

Reared from Myzus (new species) on Aguilegia, at Lafayette, Ind., by J. J. Davis.

In addition to these, Webster and Phillips ('12) have published records from St. Anthony Park, Minn., and Mesilla Park, N. Mex. The present work will add Ohio to the States in which *Aphelinus* occurs. So far it has not been found about Philadelphia, Pa., after a summer season of diligent search.

Seasonal.

The data on this point are likewise very scant. Practically all records show that *Aphelinus* appears rather late in the summer and fall. The writer did not find it about Columbus until the first of November, in spite of the fact that he was collecting aphid parasites there from the middle of September on. Mr. T. H. Parks*, who was with Webster and Phillips in Kansas during the work with the "green bug" parasites, is of the openion that *Aphelinus* does not become numerous until late fall.

Winter is probably passed in the pupal stage within the blackened remains of the host, according to the observations of Kurdjumov ('13) working with a similar species in Russia. A few attempts were made to carry it through the winter in hybernation cages outdoors in Columbus, but all failed, even though *Aphidius* confined with them emerged on the first warm days of spring. These attempts were repeated the following fall and winter in Philadelphia with no better success.

As soon as the weather began to moderate in the spring an outdoor wire-screen cage was established over some dock plants (*Rumex obtusifolius*) in which was placed a colony of parasite-free *Myzus persicæ*, together with ten or fifteen *Aphelinus semiflavus*, to note the behavior of the parasite out of doors at this season. Observations began on April 11th and continued every other day until May 13th, and then every few days until May 24th, when the experiment was closed.

On the first night after the cage was established there occurred a slight frost which numbed the parasites for a time, but they became active again as soon as the sun came out. Several warm days followed, with rather cool nights, and then about a week of cool rains followed by more warm days.

Several parasites were observed in the cage among the aphids for three or four days, when they disappeared. On the 25th of April, one live *Aphelinus* was again observed in the cage ovipositing in the aphids. Observations were made on this one intermittently until May 20th. The aphids multiplied rather slowly for the first ten days in the cage and then gradually recovered their normal rate, producing a good supply of young.

* Private communication.

In spite of the fact that live parasites were confined with these aphids for over a month during a period of rather moderate weather conditions, none of them showed the characteristic blackened appearance of parasitism.

On May 5th, fifteen aphids were dissected and one parasite egg found, which appeared just ready to hatch. Later observations, however, showed no sign of parasitism. On May 20th, more aphids were dissected in which were found three or four well grown larvæ, apparently normal. On the twenty-second, one aphid had turned black. This was the only one of the lot turning by May 24th when the experiment was closed.

While the above observations are rough and incomplete, they more than suggest a considerable influence of weather conditions on the activity and development of *Aphelinus*.

Where conditions are favorable, *Aphelinus* will multiply throughout the year; the generations following each other in cycles of 20 to 30 days, depending largely on temperature.

BIONOMICS OF ADULT.

Emergence.

Emergence takes place through an irregular rounded hole cut on the posterior-dorsal side of the blackened host remains. The fact that the emergence hole is always cut in this one particular spot, is due to the peculiar orientation of the parasite in respect to the host; the main axes of the latter being exactly vice versa to those of the former, which always bring the mouthparts of the parasite in this one position.

Locomotion.

Movement is rather sluggish in Aphelinus compared with other aphid parasites. Unless disturbed, it usually crawls deliberately about among the aphids. At times, however, it was observed to hop from one leaf to another, or from the side of the cage over onto a plant. When stimulated with a needle, it will hop away much like a flea; taking short jumps of two or three inches. Many attempts were made to goad it into sustained flight, but all were unsuccessful. In every case, it would slant downward, even when held several feet above a piece of white paper before a window. The wings are slightly reduced,

and probably are not capable of sustaining it in flight at all. On the other hand, the legs are well developed.

The above evidence would tend to discredit *Aphelinus* where rapidity of dispersion was a prerequisite for efficiency, but Mr. H. S. Smith and Harold Compere ('20) have pointed out in their work with *Aphycus lounsburyi*, an imported parasite of the black scale in California, that this is a trait in the parasite's favor where it is for local distribution by man.

Reaction to Light.

The adult *Aphelinus* is slightly positive to light, but it does not become quiescent in darkness, as shown by several experiments to determine the effect of light on oviposition, which will be taken up in detail under that heading.

Oviposition.

When the attention of *Aphelinus* is directed toward an aphid for oviposition, it moves with extreme precaution and deliberation; approaching very slowly and steadily, swaying from side to side and feeling forward with the antennæ. Just before the antennæ touch (in some cases they do touch), it halts its forward progress, sizes the situation up carefully from short range, obliques slightly, turning the head toward the aphid with a last parting look as if to make sure of the aim, position, etc., and then suddenly faces about, rising well up on the legs, thrusts the ovipositor out and downward with three or four quick backward strokes toward the victim. In the majority of cases, these miss the mark, either by the aphid moving or through poor aim. Usually they fall short and the point of the ovipositor is brought down on the substratum on which the aphid rests. If the host is in an advanced stage, the parasite may have difficulty in piercing the integument. In either case after about three or four thrusts, it will turn and repeat the act, or crawl away in search of a more favorable victim. However, if successful, it remains in position, standing well up on the legs, the ovipositor thrusts out and downward, with just the tip inserted in the host. (Plate I, Fig. 2). This position is often maintained for several minutes. In fact, some were observed to last as long as fifteen minutes, and repeated twice in succession for a like period without depositing a single egg.

In the majority of instances, the aphid appears undisturbed while oviposition is going on. This is especially true of the younger stages. However, there are times when the slightest touch with the antennæ or a prick with the ovipositor will cause them to kick up and make off. If this happens when the ovipositor is fastened in one of the larger stages, it drags the parasite with it. If the host is smaller, however, the parasite is able to master it and keep it in place in spite of its struggles. This is done by the parasite standing well up on its legs and holding up the victim slightly so that it cannot get a firm foothold on the substratum. The ovipositor is held in place during the struggle by the presence of three retractile barbs near the tip. These function so efficiently that the parasite itself often has difficulty in getting free, often having to brace the hind legs against the aphid and give several vigorous pulls before it is withdrawn. At times, the ovipositor may be fixed so firmly in place that it permits a larger host to drag the parasite about so violently that injury results. Several times *Aphelinus* has been observed in a crippled condition after getting free from one of these encounters. In this condition, the ovipositor remains extruded, the parasite not having the power to retract the abdominal segments that bring it back in position, and the individual goes stumbling off with head down and abdomen elevated until it topples over apparently dead.

The ovipositor is usually inserted on the dorsal surface of the host's abdomen, but almost any other part of the body may be chosen, depending on the point of approach. Many times it has been observed on the head between the antennæ, and among *Macrosiphum pisi* on clover, a large species that stands at a considerable angle from the plant, well up on its long legs, the parasite was observed to attack it from beneath, elevating the ovipositor well up and making contact with the ventral surface of the abdomen.

Stage of Host Preferred.—A distinct preference was early shown for the younger stages of aphids. In order to determine this more exactly, several experiments were planned and carried out. Some difficulty, however, was encountered in eliminating a number of factors that might alter a true expression of this preference. These factors were the variation in numbers of the different stages available for oviposition; the high mortality of

the first and second stage nymphs after being parasitized; and the difficulty of handling large numbers of the various stages of aphids necessary to obtain accurate results.

At first a large number of parasites were placed with a greater number of aphids, in the different stages, for a short time and then removed. An equal number of aphids, representing the different stages, were then isolated and the parasites allowed to develop in these until they showed externally. These parasitized individuals were then counted and the percentage taken to indicate the preference of the parasite for a given stage. (See Table I.).

TABLE I.

Showing the Percent of Parasitism in the Various Instars of the Aphid Host, Reared Through Until It Appeared.

No. Aphids Used	Instars	No. Parasitized	Percent.
100	1–2	26	26
100	2–3	16	16
75	4–adult	5	6.6

This method was unsatisfactory, as it did not account for the death of a large number of the smaller stages, which would lower the percentage considerably for that group. It also did not necessarily provide an equal number of the various stages, either at the beginning or the end, to eliminate chance. Then finally the separating and keeping the aphids in different cages for any length of time always made possible the death and escape of many specimens that could not be accounted for.

To get around these difficulties, the following modifications were introduced: As nearly equal and smaller numbers of the different stages were placed together with a number of parasites for a day or so and then all were dissected. The percent parasitized in the various groups, as indicated by the presence of the parasite's egg, showed fairly accurately the preference for that particular stage. Three separate lots were thus treated with the results shown in Table II.

The extreme rarity of parasitism in the adult aphids was clearly demonstrated in the experiments to determine the effect of parasitism on the production of young, in which it was neces-

sary to bring about a parasitized condition in the adult after she had started to produce young. Out of many trials to bring this about, but three were successful; notwithstanding the fact that several parasites were confined for days with the adult aphids time and again.

It is believed that several factors operate here to determine this preference for the younger stages of the host; namely (1) size, it being easier to ovipost in a small aphid than a large one, due to position alone; (2) irritability, the large aphids are

TABLE II.

Showing the Percent of Parasitism in the Various Instars, Dissected Immediately After the Parasites Were Removed.

Approx. Instar	No. Dissected			No. Parasitized			Percent Parasitized		
	Lot 1	Lot 2	Lot 3	Lot 1	Lot 2	Lot 3	Lot 1	Lot 2	Lot 3
1–2	90	105	42	54	58	19	60	55.7	45.2
3–4	161	84	57	66	26	20	41	31	35
4–5	62	61	19	10	4	1	16	6.9	5.2

more irritable than the small nymphs, which often renders oviposition impossible; and (3) toughness of the integument which makes it difficult for the ovipositor to penetrate.

Number of Eggs per Host.—In more than 3,000 separate dissections for egg counts, etc., there were only two or three cases where more than one egg was deposited in a single host. These few exceptions occurred only where a number of parasites were confined with a few aphids for several days, and even then no more than two eggs were ever found in a single host. In some of these trials a parasitism of 100 percent was obtained for 20 first to third instar nymphs confined with one parasite for a single day of twelve hours. Instances were observed several times where parasites apparently oviposited in hosts already parasitized, even to the blackened condition; but in no case did subsequent dissection show that an egg was deposited. *Aphelinus* has also been observed to return several times to a single host, but here, likewise, only a single egg is left, or in many cases none at all.

The above observations seem to indicate that *Aphelinus* places but one egg in a host, but that it is incapable of determining whether a given host harbors a parasite already until the ovipositor is inserted. The above habit is decidedly in its favor when its efficiency as a parasite is considered in contrast to some of the more wasteful species like *Aphidius*, which generally places a number of eggs in a single host, but only one of the resulting larvæ matures.

Number of Eggs Laid per Day and Night.—To determine the number of eggs laid per day and night over the period of egg production, experiments were carried out with a single *Aphelinus* confined with a given number of nymphs from the first to the third instar. Dissections were made on these both in the evening and morning, and a fresh supply of parasite-free aphids placed in the cage for the parasite to oviposit in for the succeeding period. During the night, the cages were kept in a dark chamber so that practically absolute darkness prevailed until the time came to change to light. As nearly equal periods of light and darkness were obtained as was possible; likewise, other factors, such as temperature and humidity, were fairly uniform. All experiments were carried out in room 107 of the Botany and Zoology Building, in a temperature of from 70 to 75 degrees.

Owing to the extreme minuteness of the specimens dealt with, considerable difficulty was experienced in carrying a single parasite through its total life without its escaping or being accidently killed in handling. This was so great that only one specimen went through its total period of egg production to a natural death. Two others were carried for seventeen and eighteen days respectively before they escaped or were accidentally killed. The results of these experiments appear graphically in Figure 1.

Feeding.

It is quite evident from observations made that the commonest means of sustaining life in the adult *Aphelinus* is by its habit of feeding at the puncture holes made by the ovipositor in the young aphids.

This habit is not restricted to *Aphelinus* alone, but seems to be rather common among chalcid parasites in general. The

records with which the writer is familiar date from Howard ('08), where he quotes Dr. Marchal's observations on this habit in the parasite *Tetrastichus xanthomelænæ* Rond, on the eggs of the elm leaf beetle *Galerucella luteola*. Later Howard ('10) in a more general article on this habit among the Chalcidoidea, again refers to Marchal's observations on *Tetrastichus*, in addition to some similar observations on *Aphelinus mytilaspidis* in *Aspidiotus ostreæformis*, along with several others; namely, Dr. H. T. Fernald on *Tetrastichus asparagi*, feeding on the eggs

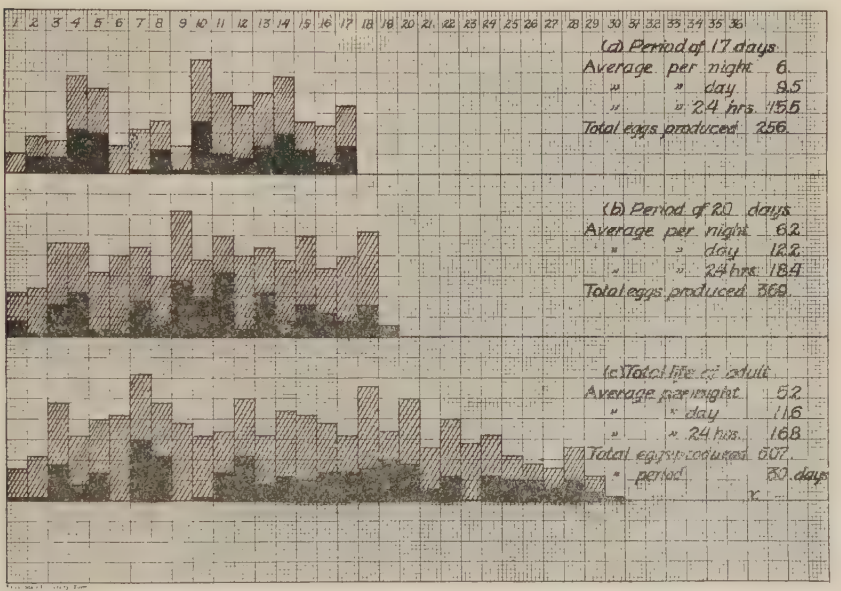
(a) Period of 17 days
Average per night 6.
" " day 9.5
" " 24 hrs. 15.5
Total eggs produced 256.
(b) Period of 20 days
Average per night 6.2
" " day 12.2
" " 24 hrs. 18.4
Total eggs produced 368.
(c) Total life of adult
Average per night 5.2
" " day 11.6
" " 24 hrs. 16.8
Total eggs produced 607.
" period 30 days

Fig. 1. *Number of eggs deposited by a single Aphelinus semiflavus per day and night for a given period.* Black equals night, cross lines equals day; large squares on abscissa equal 24 hours; small squares on ordinate equals one egg; "x" equals point where natural death occurred.

of the asparagus beetle (*Crioceris asparagi*), and Mr. J. G. Sanders concerning *Aphelinus fuscipennis* on *Aspidiotus* rapax. Mr. H. J. Quayle ('10) also refers to a similar habit as occurring rarely in *Aphelinus diaspidis*, parasite of the red or orange scale (*Chrysomphalus aurantii*) in California. He also observed this species to feed on honey dew, plant juices, and fruit. Mr. L. P. Rockwood ('17) published for the first time observations on this habit in *Aphelinus lapisligni* How., feeding at the

puncture holes in *Aphis bakeri*, in which the actions are described in some detail.

A number of the above cited observations have been verified, by the writer, on *Aphelinus semiflavus*, and additional data have been secured on this interesting feeding habit.

These parasites confined in glass vials or other receptacles without food or water were noticed to live but two or three days at most; while those among aphids lived a much longer time (two weeks or more). This species had also been observed feeding at the puncture holes made by the ovipositor in aphids. In addition to this aphid-feeding habit, the writer was interested to know whether they fed on any other substance, and if so, how long they would live on the various kinds of food that might be available. This point was thought to have considerable bearing on methods of handling and transporting species to be used in an economic way for the suppression of injurious forms.

Several experiments were undertaken to test out the effect of various foods on the length of life of adult Aphelini. Specimens emerging at the same time were placed in cages as follows: One lot on dock (*Rumex obtusifolius*) only, in a lantern globe cage; another with four or five large aphids not yet producing young; still another on a dock plant to which leaves covered with honey-dew were added every other day; and lastly, a lot on a plant with honey solution added every day. All were confined in lantern globe cages with growing dock plants in room 107 of the Botany and Zoology Building. The results appear in Table III.

Some careful observations were made on *Aphelinus semiflavus* in the act of feeding at the puncture holes made by its ovipositor in aphid nymphs. To confine the specimens so that they could be easily observed under a binocular microscope, two hollow ground slides were used with the aphids and parasite in the space between them on a bit of leaf. Four or five 2-instar nymphs were thus enclosed with one female *Aphelinus*. Oviposition began immediately after they were placed together, and was repeated several times in the same aphid, after which the victim was noticed to droop down in a sickly condition. In this state the parasite approached and carefully examined the aphid with its antennæ. Being apparently satisfied, it placed its forefeet on the victim's back and its mouthparts to the puncture.

This position was then held for several minutes without moving, during which the body of the aphid was noticed to slowly collapse. After it was apparently sucked dry, *Aphelinus* would withdraw and search out another victim where the same maneuvers were repeated. Three small nymphs were thus fed upon in half an hour, after which the parasite's abdomen appeared quite distended with their contents.

These dead aphids were later dissected, and it was found that *Aphelinus* had deposited an egg in each. This would seem to indicate that oviposition was the primary object in puncturing a host, and that feeding was a secondary, acquired habit.

TABLE III.

Effect of Different Food, Accessible, on Length of Life in the Adult Parasites.

Food	Number of Parasites	Length of Life
Dock plant	3	3 days
4th instar aphids	3	4 days
Honey-dew (on leaves)	3	11–12 days
Honey solution (fresh)	1	39 days

However, with this habit of feeding, the parasite defeats its primary purpose by killing the host and preventing the development of the egg immediately after it is deposited.

Observations made in the course of other experiments show that a single parasite ordinarily kills, in the above manner, from three to five of the smaller instars per day. The very young stages are almost always preferred, although it has been noticed to feed on a third or fourth instar nymph. That the older stages are seldom if ever attacked, has been demonstrated in a number of instances where *Aphelinus* was confined with adult aphids for various purposes. The parasite not only failed to oviposit in these adults, but actually died with them for want of food when the adult aphids did not produce young for it to feed on. In all cases the aphid is very much weakened so as to offer practically no resistance, before the parasite will attempt to feed. While the feeding is going on, the aphid

remains slumped down apparently oblivious to the slow ebbing away of its life blood, the only movement being a slight wave of a leg or antenna.

Length of Adult Stage.

The length of life in the adult has been observed to vary according to the kind of food available. Temperature also is undoubtedly an important factor, but no accurate experiments have been attempted to show how it operates.

The effect of the different kinds of food on the length of life is shown in Table III, and may be briefly summarized as follows: Confined without food, on plants alone, among older aphids on plants, or in small receptacles, death ensues in less than four days; on honey dew they live for twelve days; and one specimen was kept alive for thirty-nine days on honey solution in distilled water, given fresh every day until it finally escaped. There is reason to believe that they will live much longer on this. The only one carried through to normal death on aphids, lived thirty-six days; producing eggs for thirty of these days.

REPRODUCTION AND DEVELOPMENT.

Method.

The prevailing method of reproduction in *Aphelinus semiflavus*, as well as in a number of other chalcid parasites, is by parthenogenesis. Seventeen successive generations have thus far been reared parthenogenetically, and there is every reason to expect many more to follow indefinitely; since the last offspring appear as vigorous as the first.

Proportion of Sexes.

Males are quite rare in this species. Out of more than 900 individuals examined from the different generations throughout the series of parthenogenetic generations, but seven males were found. These were scattered more or less irregularly through the series as shown in Table IV. It is quite possible that males might have appeared from time to time in other rearings and passed unnoticed, due to the difficulty of distinguishing the sexes without a microscope. However, throughout all the observations, of either living or dead material, males

were encountered but one other time, when three were taken from Cage 48a3 on March 2, 1921. One of these was confined with females among some aphids on a dock leaf in a small vial, and copulation was observed. No observations were made on mated females to determine whether mating had any effect on the proportion of sexes and number of offspring produced. This must be left for later investigation.

TABLE IV.

Sample Counts from a Series of Parthenogenetic Generations Showing Proportion of Sexes.

Generation.....	a_1	b_1	c_1	d_2	e_1	f_1	g_2	h_1	i_2	j_2	k_1	l_1	m_2	n_1	o_1	p_1	q_2
Date.....	3–6 1921	3–22 1921	4–3 1921	5–4 1921	5–23 1921	6–7 1921	6–23 1921	6–29 1921	8–11 1921	9–1 1921	9–24 1921	9–20 1921	10–30 1921	11–19 1921	11–27 1921	12–13 1921	1–30 1922
No. Females...	66	38	61	135	55	59	15	8	132	113	81	6	74	57	1	12	8
No. Males.....	0	0	0	3	0	0	0	0	0	1	3	0	0	0	0	0	0

Some of the Encyrtidæ, a family of scale parasites, closely related to the Eulophidæ, produce but few males or none at all. In other species of the genus *Aphelinus*, feeding on aphids, the males are not known.

The production of females parthenogentically that are capable of producing more females in the same manner, for an indefinite number of generations, is a very valuable asset to a parasite when it is to be established in new territory. By this method of reproduction the chances of its increase are greatly enhanced. Likewise, it is less liable to die out through reduction in numbers and consequent scattering of individuals that would reduce the chances of mating where this was important for the perpetuation of the race.

The Egg.

Description.—The egg is elongate ovate, and slightly bent in the middle, with dimensions of .21 x .05 mm. The anterior end is slightly more rounded than the posterior, which tapers bluntly to a point. At the anterior end, there also appears a small nipple-like micropyle that projects just far enough from the surface to be seen with a high power compound microscope. The color, in reflected light, is a very light cream-white; darker

in transmitted light. The corion is very thin and transparent; showing the finely granular structure of the contents, which is homogeneous throughout for a few hours after the egg is laid. Soon development begins to appear by the characteristic form of the growing embryo. At the end of twenty-four hours the egg clears up slightly, except for certain parts of the embryo, which show darker in the form of two blotches; the one in the anterior portion of the egg having a long and wavy form which bends around like a hook near the end of the egg; the other in the posterior portion is more rounded. Both of these blotches finally join together by the growth of the mesenteron, shown by two faint lines. When the egg is forty-six to forty-eight hours old, it becomes still more transparent, and only one elliptical dark spot appears near the center. It is now almost ready to hatch. (See Figs. 3, 4, and 5, Plate I.).

Position in Host.—The egg floats loose in the hæmocœl of the host, where it may be seen on dissection under the high-power of a binocular microscope. It is quite large in size compared with the size of the adult.

Length of Stage.—The period of time spent in the egg stage is very near three days (72 hours) for all the observations.

Number Laid.—The only actual count made of the number of eggs laid by a single individual in the course of its life, gave 507. (Fig. 1). Other partial counts would lead one to believe that this is a good high average. The conditions under which the eggs were deposited may be considered almost optimum, since the parasite was closely confined with a number of parasite-free aphids of the most desirable stage. It is difficult to make an estimate of what the total number would be under more natural conditions out of doors, but it is probably much less than the actual counts indicate for caged material. From the number of blackened aphids obtained from the different cages, one might estimate the total number parasitized by one adult female to be around 200.

Like many other parasitic Hymenoptera, there are only a few mature eggs in the ovarian tubes at a time; about ten for *Aphelinus*. The other eggs mature from day to day in such numbers as required, which is probably regulated by some external stimulus, like the presence of a large number of hosts.

Larva.

Description.—The larva when first hatched has practically the same size and form as the egg, but slightly shorter and broader. As growth proceeds the anterior and middle segments enlarge to accommodate the increasing mesenteron, giving it at first a spindle form and later a distinct top shape; the head forming a knob on the broad rounded anterior end, and the posterior tapering to a rounded point. When the larva reaches maturity it is contracted more in a longitudinal direction, becoming almost globular in general shape. (Fig. 7, Plate I).

In the younger stages the color is almost absent, except the dark mesenteron which stands out against the general transparency. Later on the accumulating fat body lends a light yellow color to the larva.

The segmentation of the larva is rather obscure, but with careful search thirteen may be counted. The head is distinct, supported by a visible tentorium, and bearing a mouth opening in the anterior ventral portion. This mouth is armed with two sharp dark mandibles which are situated well back in the cavity, but are capable of protrusion sufficient for grasping purposes. A peculiar botryoidal structure may be also observed covering the front and vertex. (Fig. 8, Plate I). This is probably a group of sensory organs. The entire digestive tract may be traced from mouth to anus in transmitted light; though the fore and hind guts-are indistinct. Several other internal organs were slightly visible, but no attempt was made to identify them. Spiracles are observable on segments five to nine inclusive, but could not be seen on any of the others. Small tracheæ lead off from these, but it was not determined whether they function or not.

Position in Host.—During most of the growing period the larva occupies no definite position in the host, but moves freely about in the fluid of the body cavity. However, when it has devoured most of the internal organs of the host and has become large enough to fill the abdominal cavity it assumes a position with its primary axes similar to those of the host. Just before pupation this position is exactly reversed, so that the primary axes of the parasite are opposite to those of the host, both anterior-posteriorly and dorso-ventrally.

Length of Stage.—The larval period varies from about six to eleven days, or even longer in some cases where the temperature is low. The usual time from egg deposition until the aphid host turned black, was nine to ten days. Pupation began within one or two days after the host turned black, and by the end of three days the last larval skin was cast and the full pupal form assumed.

It was found that it took two days longer for the larva to kill and turn black an adult aphid than it did for a third instar nymph, and one day longer for a first instar nymph than for a third instar. This would seem to indicate that the medium instars furnished optimum conditions for the development of the larva, where other factors were equal.

Pupa.

Description.—The pupa is characteristic of the Hymenoptera in general, *i. e.*, of a form similar to the adult, with rudimentary wings, and large turgid legs and antennæ lying near the body on the ventral side, and enclosed in transparent sheaths. When first formed the pupa is almost transparent or very light yellow throughout. Soon the eyes turn to a reddish brown and the light yellow deepens with age until the colors of the adult are reached at maturity.

Meconia.—As soon as the pupa begins to take form, or just before it sheds the last larval skin, it voids several brown bodies of an oval shape. These are the characteristic meconia of the parasitic Hymenoptera, and represent the total, larval excrement that has accumulated throughout the period and discharged at this time.

Position.—The position of the pupa with reference to the host is exactly opposite to the primary axes of the latter, the same as described for the mature larva. This places the mouth parts of the adult *Aphelinus* in a position to gnaw out the emergence hole on the posterior-dorsal surface of the blackened host remains.

Length of Stage.—The average length of the pupal stage is seven to eight days, but it may vary between five and fifteen days, or even longer under adverse conditions. There is every reason to believe that it passes the winter in this stage.

Effect of Parasite on Host.

On Internal Structures.—As soon as the young *Aphelinus* larva hatches, it begins feeding on the fat body and developing young of the host. Within three or four days after hatching nearly all the young aphids within the mother are destroyed. The feeding continues on the other structures, until nothing is left, when the parasite larva approaches maturity, but the digestive tract. This is in common with the habits of other parasitic Hymenoptera larva which spare the vital organs of the host until the very last.

The larva of Aphelinus is armed with well developed mandibles, which, however, do not project out of the mouth as in the larva of the Braconid parasite, *Aphidius;* but seem situated back in the mouth cavity where they are less effective in tearing up host tissue. There is no gathering of bunches of fat globules in a host parasitized by *Aphelinus*, as in one harboring *Aphidius*, which would indicate that the fat cells are not broken down. However, many bits of tissue and separate cells may be observed floating promiscuously around in the body fluids of a host parasitized by *Aphelinus*.

On External Appearance.—The first external appearance of parasitism is a change in color of the host from green to light cream. Then a honey-colored spot appears in the abdomen, which is the darker mesenteron of the larval parasite within. This light color of the host deepens into a yellow or light amber in another day, and by the following day begins to turn gray. Within a very few hours after graying begins, the aphid is coal-black, except for the head and appendages, which are transparent. Death occurs during this last darkening. Just before death the aphid spreads out its legs in symmetrical form and firmly grasps the plant on which it rests. This tends to make them adhere to the plant after death; still, they are further secured by some form of silk secretion through the ventral wall. No detailed observations were made on this act, but it is evident that no hole is cut through, as in *Aphidius*. Perhaps only a very small puncture is made and the silk forced through it. The amount is very small, at most, and in some cases there is not enough to detect; nevertheless, the black aphid remains adhere quite firmly to the substratum.

On Production of Young.—Several experiments were undertaken to determine the effect of parasitism in the various instars on their subsequent maturity and production of young. An equal number of parasites were confined with separate lots of different ages and instars of aphids for a day and then removed. The aphids were observed until they showed parasitism and died. One nymph, parasitized on the day it was born, carried the parasite through to maturity, but did not mature itself, or produce any young. Three nymphs, parasitized in the second instar, produced but one young, which was doubtfully from one of these nymphs, since another unparasitized one occurred in the same cage. Nine second instar nymphs matured and produced but two young at the end of eleven days from birth. Seven nymphs, parasitized in the third instar, matured and produced sixteen young before succumbing to the parasite. With the larger stages, parasitism was so rare that no data were obtained.

It appears from these experiments that those aphids parasitized in the second instar seldom mature and produce young; while those parasitized in the third instar may mature and produce several young before they are killed.

In the few cases where adult aphids were parasitized after they had begun to produce young, the production continued for six days from the time the parasite's egg was deposited. During this time two females produced twenty-five young. Allowing three days for the egg of *Aphelinus* to hatch, it will be seen (Fig. 2, curve "d") that the decline in production of young began shortly after the egg hatched. Production ceased altogether two days before the death of the host.

Aphelinus may also disturb the production of young in aphids by worrying or exciting the viviparous females. This is shown in Figure 2, curves a, b, and d, between the points x and x_1 where the parasites were introduced and removed. In every case a marked drop occurs in the production. However, as soon as a few young are born, the parasite's attention is directed to them so that the adults may go on producing others unmolested. Here is where the preference of *Aphelinus* for the younger stages of the host is of marked significance as a factor in their control, since it does not attack at the source of production, the adult female. This may account for the fact that *Aphelinus* is much slower than *Aphidius* in exterminating a colony of aphids with which they are confined.

Effect of Host on Parasite.

As in common with most parasitic Hymenoptera, there is a great variation in size of adults according to food supply or size of host. This was more than double in *Aphelinus*, or from .35 mm. to .75 mm. in length. The extremely small specimens were apparently sterile, for several trials on parasite-free nymphs failed to get them to reproduce, or even lay eggs. An attempt at oviposition was noticed in one case, but the parasite was unable to extrude the ovipositor its full length.

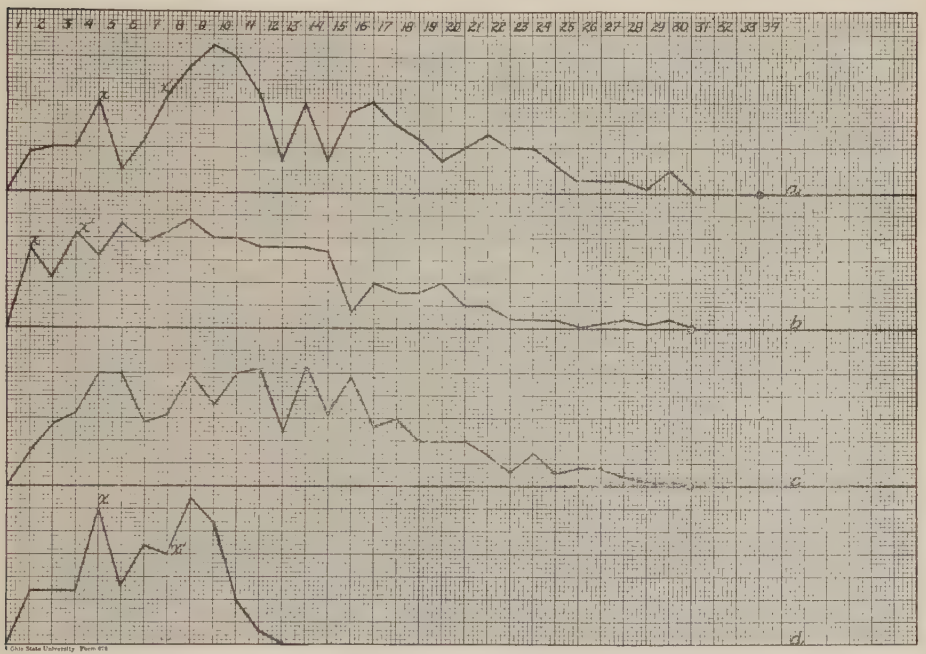

Fig. 2. *A series of curves showing the effect of the parasite Aphelinus semiflavus on the production of young in adult viviparous Myzus persicæ. a.* Average daily production of young in six females for the average total period of production, with *Aphelinus* but unparasitized (note drop in curve between x and x_1 when parasites were introduced, showing effect of the presence of *Aphelinus* on production of young); *b.* average daily production of young in ten females for the average total period of production with *Aphelinus* but unparasitized. (note drop between x and x_1 as in *a*); c. average daily production of young in ten females free from parasites; d. average daily production of young in two females for the average total period of production before and after parasitism. The parasites were introduced at the point x and removed at x_1. Death from parasitism occurred at the end of he curve.

COHOSTS.

Previous records give *Myzus persicæ* Sulz., *Aphis gossypii*(?) Glover, *Aphis maidis* Fitch, and *Chaitophorus viminalis* Mon., as hosts for *Aphelinus semiflavus*. The writer can add to this list from his own rearings, the following: *Macrosiphum pisi* Kalt., *M. granarium* Kirby, *M. Sanborni* Gillett, rarely, and *Anuraphis viburnicola* Gillett.

Myzus persicæ, from which most of the field records come, seems to be the preferred host, although it took to *Macrosiphum granarium* and *Anuraphis viburnicola* quite as readily in captivity. *Macrosiphum pisi* was not parasitized very heavily, due, perhaps to its long legs and large size, and irritability. *Macrosiphum sanborni* escaped almost entirely for no apparent reason. They were only rarely attacked even when confined in a cage with a number of parasites, and a colony went through the winter in the greenhouse among many parasites with but a scarce eight or ten being parasitized.

Several attempts were made to rear *Aphelinus* in *Aphis rumicis*, another common dock aphid, but all were unsuccessful. The parasite would oviposit in them freely, and subsequent dissection showed that the eggs would hatch and the larva become nearly half grown, in some cases; but they would always die before reaching maturity. In most cases death occurred shortly after the egg hatched.

INTERRELATIONS WITH APHIDIUS.

Considerable importance has been attached to the interrelations of primary parasites in a single host, since the discovery by Pemberton and Willard (18) of the disastrous results of the interrelations of two primary fruit fly parasites imported to the Hawaiian Islands.

From what is known of the two groups of primary aphid parasites, there seems to be no question about the superiority of *Aphidius* over *Aphelinus* as a controlling factor for aphids. It not only appears earlier in the season, but lays more eggs in a shorter time, is more vigorous in its actions, is not confined so closely to the younger aphids, and has a much greater dispersal than *Aphelinus*. It was, therefore, both interesting and important to determine to what extent these two occurred in the same host, and the ultimate outcome of such occurrence.

Observations on colonies of aphids in the open greenhouse among both *Aphidius* and *Aphelinus* showed that parasitism of a single host by both parasites was rare at best, if not entierly absent. In fact, it was often difficult to bring this about when they were confined in a small cage. However, when they were put in and taken out separately, the one before the other, results were different. *Aphidius* would parasitize practically every aphid in a small colony, and all the eggs that *Aphelinus* would deposit later, which was always considerably less than *Aphidius* for a given period, would be in the same host with one or more *Aphidius* eggs or larvæ.

When *Aphidius* was placed with a colony of aphids a day ahead of *Aphelinus* and removed before *Aphelinus* was introduced, a heavy parasitism by both resulted. But in practically every case, the *Aphelinus* eggs failed to hatch. The conditions were then reversed, and *Aphelinus* was given a day's start. In this case *Aphelinus* hatched and began development in the usual way, but they did not interfere in the least with *Aphidius* which came along later. This very efficient parasite emerged from its membraneous cover in the normal manner and within a day or two the small *Aphelinus* larva would die. This happened even when the *Aphelinus* larva was allowed several days the advantage over *Aphidius* and was quite large when the latter hatched.

It was, therefore, practically established that for the younger instars, at least, *Aphidius* would always dominate, regardless of whether it came before or after *Aphelinus* in the same host; and that *Aphelinus*, coming after *Aphidius* for a day, would never hatch. In fact, the egg would never begin development as shown in the characteristic change in appearance (Plate I, Fig. 3, 4 and 5.)

Possible Ways by Which Aphidius May Cause the Death of Aphelinus.

Just how the death of *Aphelinus* is brought about still remains a mystery that will only be solved by more careful investigation. Several theories are suggested to explain it, but all of them require refined methods to prove. They are given here for what they are worth.

Cannibalism.—*Aphidius* is much better armed with mandibles and a spiny body, than *Aphelinus*, and is also more active. It might, therefore, be expected to kill *Aphelinus* by feeding directly on it or injuring it fatally by striking against it in the host. Yet, in the many cases that were examined, *Aphidius* was never found feeding on *Aphelinus*, nor did there ever appear evidence of mutilation in the dead larvæ. In each case, *Aphelinus* simply stopped movement and turned darker in color, in which condition it remained until it finally shriveled up and disintegrated.

Starvation.—This theory does not carry much weight when we consider the abundant supply of food present at the time of death.

Toxic Substance.—It is quite possible that something of this nature may be thrown off by *Aphidius* that has an injurious effect on *Aphelinus*, but it is difficult to prove.

Lack of Oxygen.—Our knowledge of respiration in this group of parasites is still very meager, so it is scarcely possible to say just how the above condition might effect the parasites. It appears that both derive their oxygen from the blood of the host, in which they float, and it is also possible that *Aphidius*, being the more active of the two and better adapted for breathing might get around and monopolize it; though it is doubtful if this could be reduced low enough to kill *Aphelinus* and not work permanent injury on *Aphidius*.

Economic Importance.

While the above theories are of considerable importance from a biological standpoint, it is sufficient for economic purposes simply to know which of the two parasites will dominate when the two come together. This the writer has shown. Since *Aphidius* is the more efficient one in every respect, there need be little fear over the fact that it will kill *Aphelinus*, since this efficiency will in no way be lessened where they accidentally come together. The aphids that *Aphelinus* parasitized would not interfere with *Aphidius*, and would be so many more dead aphids in addition to those killed by *Aphidius*.

SECONDARY PARASITES.

Throughout most of the winter of 1921–22, at Columbus, Ohio, very few secondary parasites appeared to infest *Aphelinus* in the greenhouse insectary. But by February, two species began to appear in from ten to twenty percent of the specimens taken in the open greenhouse. One was determined by Mr. Gahan of the United States National Museum, as *Asaphes* (*Megorismus*) *americana* Gir., and the other by Mr. Rowher, also of the Museum, as *Alloxysta* sp., a Figitid resembling *Charips* (*Allottria*).

In the fall of 1921, another secondary was reared from a new species of *Aphelinus* on a juniper aphid near Philadelphia, Pennsylvania, which likewise proved to be a secondary of *Aphelinus semiflavus*. This was determined by Mr. Gahan as *Aphidencyrtus aphidiphagus* Ashm.

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EXPLANATION OF PLATE.

Fig. 1. Adult female *Aphelinus semiflavus* with male antenna and genitalia in insert.
Fig. 2. Female *Aphelinus* ovipositing in aphid nymph.
Fig. 3. Egg less than five hours old.
Fig. 4. Egg twenty-four to twenty-eight hours old.
Fig. 5. Egg forty-six to forty-eight hours old.
Fig. 6. Small larva just hatched.
Fig. 7. Lateral view of full grown larva, just before pupation.
Fig. 8. Front view of larval head, greatly enlarged.

All figures, except Figure 8, are drawn approximately to the same scale, enlarged thirty-three and a third times.

E. A. Hartley.

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